ASSESSMENT OF PUBLIC HEALTH RISK ASSOCIATED WITH RADIOACTIVE AIR EMISSIONS FROM TWO MINNESOTA NUCLEAR POWER PLANTS

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1. Introduction

The available information concerning radiation doses and effects is examined in this report to determine whether airborne releases of radionuclides at the Monticello and Prairie Island Nuclear Generating Plants in Minnesota pose a risk to the health and safety of the public. This evaluation was performed for the Minnesota Pollution Control Agency. Two separate activities were involved: (1) considering the information related to computing and confirming the maximum and collective radiation dose commitments due to airborne effluent from the two stations, and (2) reviewing the recommendations and their basis for relating radiation doses to the type and number of adverse health effects. A companion report examines the systems for releasing and monitoring airborne effluent at the two stations and the available control technology for attaining population doses due to releases "as low as reasonably achievable."

The radiation doses to persons from the two stations are examined in Section 2 on the basis of measured radionuclide releases in 1979, calculations of maximum and collective doses based on these releases and confirmation through environmental monitoring of the radionuclide and radiation levels predicted in the calculations. Major and secondary pathways and radionuclides are identified. The information provided by the operator is checked by comparison with radionuclide releases observed at other stations or computed from generic operational parameters; with transfer calculations performed by others and transfer factors recommended by others; and with environmental monitoring performed by state agencies. Alternate values are discussed and an extensive set of references is provided for documents that present this information. Additional measurements and surveys are recommended where information is currently not available concerning annual releases of certain radionuclides, site-specific transfer parameters, levels of these radionuclides in environmental media, and the existence and magnitude of possible pathways.

The incidence of somatic and genetic biological effects relative to the radiation dose to persons is discussed in Section 3. These values are taken from assessments by expert groups based on a few major epidemiological studies and refer to genetic damages and various forms of cancer that result in either illness or death. Uncertainties as well as major and passionate disagreements concerning the incidence of adverse health effects are indicated. Sources of information concerning these conclusions and disagreements are cited, and some reasons for differences in opinion are noted. The selected values of incidence of genetic and somatic effects are applied to the collective dose commitments presented in Section 2 as a result of the operation of the two stations to compute the risk to the public.

2. Radiation Exposure to Members of the Public

2.1 Overview

All commercial nuclear power stations in the United States routinely discharge radioactive gases and airborne particles during releases of gaseous wastes and of ventilating air. These radionuclides are sources of radiation exposure to the population by various pathways, notably external exposure from radionuclides suspended in air and deposited on surfaces, and internal exposure after inhalation and after ingestion of foods into which radionuclides have passed. The station operator is required by the U.S. Nuclear Regulatory Commission (NRC) to monitor and report these radioactive releases, to estimate radiation exposures to persons from effluents, to maintain these exposures as low as reasonably achievable ("ALARA"), and to monitor and report environmental radiation and radioactivity levels.

Radiation exposure to persons outside the station is computed on the basis of radionuclide release rates and pathway transfer models. Radiation and radionuclide levels in the environment are usually too low relative to the natural radiation background and fallout from atmospheric nuclear tests for reliable direct measurements of exposure to persons. The calculated doses are only approximate, however, because of the many pathways and radionuclides to be considered and the wide range in values of applied transfer, uptake, and dose parameters. Section 2 of this report evaluates exposure values computed by the station operator by examining the generally applied ("generic") calculational source term and pathway models and the results of measurements performed at the two stations in Minnesota.

Information from the station operator concerning population radiation exposure is presented in Section 2.2. This information consists of annual airborne radionuclide releases for 1979 reported to the NRC (NS 79, NS 79a); an assessment of the collective dose commitment to persons within 50 miles (80 km) of each station and of the dose commitment to maximum exposed individuals near each station in 1979 (NS 80); and environmental radiological monitoring data related to airborne effluents at the two stations in 1979 reported to the NRC (NS 80a, NS 80b). The maximum dose commitments for individuals are calculated for evaluating compliance with radionuclide release limits under 10 CFR Part 20 and with design objectives and operating limits under 10 CFR Part 50, Appendix I. The collective dose commitment values provide a means of comparing the radiological impacts of these stations with others, computing genetic effects, and estimating somatic effects on the basis of hypotheses relating effects to doses at low levels. The environmental radiological monitoring results are used to examine the impact of station operation and to test transfer parameters, at least in terms of upper limits.

The generic basis for the measurements and calculations is examined in Section 2.3. The set of radionuclides that the operator monitors at release points in accord with the technical specifications for the station (RS 74) has been determined from experience and from detailed considerations of sources and pathways within the station (RS 73, SD 76, SD 76a, Be 79). For computing doses, a set of calculational models and associated transfer, uptake, and dose parameters that are acceptable to the NRC and are used by most station operators, including the operator of Monticello and Prairie Island, are presented in Regulatory Guides 1.109 (SD 77) and 1.111 (SD 77a). The environmental monitoring program is defined by technical specifications to obtain measurements of indicator media in important pathways at levels that confirm compliance with dose limits (SD 75, SD 75a).

Reevaluation of the data that underlie the selected parameters and reported newer data have prompted several recommendations of different parameter values (Ho 79, Ng 79, Br 79). Moreover, the reliability of entire calculational models for specific pathways has been called into question, (Li 79, Mi 79, Br 79) and one of these evaluations (Br 79) predicted radiation exposures to the maximally exposed persons at a proposed station that are many orders of magnitude higher than according to the models in current use. The available information is used here to consider whether the source terms and transfer calculations applied by the station operator are sufficiently complete and appropriate in terms of generic knowledge to yield dependable dose calculations and avoid serious underestimates at the two Minnesota stations.

In Section 2.4, the effluent measurements, dose calculations, and environmental monitoring results presented in Section 2.2 are reviewed. Omissions in effluent radionuclide measurements are identified on the basis of effluents predicted in Section 2.3 and measurements performed at similar stations during studies of source terms (Pe 73, Pe 78, Ka 74, Bl 76). Dose commitments calculated by two other computer programs are compared with the results of the calculations by the operator. The environmental monitoring results are used to estimate upper limits for some transfer parameters and for radiation doses due to station operation. Results of studies and routine monitoring performed near the stations are also used to test the calculational models and derive factors that are applicable to the sites.

The conclusions concerning the collective and maximum individual dose commitment values are presented in Section 2.5 for ALARA considerations and application in computing health effects. Actions are recommended for improving the dosimetric data base and assuring confidence in it.

2.2 Radiation Dose Information from the Station Operator

2.2.1 Monticello Nuclear Generating Plant

Airborne Releases. The Monticello Nuclear Generating Plant is operated by the Northern States Power Company. It has a boiling water reactor (BWR) at a licensed level of 1670 megawatt thermal. The station is located in flat terrain on the west bank of the Mississippi River near the town of Monticello, Minnesota, approximately 40 miles northwest of Minneapolis-St. Paul. According to the population estimate by the operator for 1980, 16 persons live within 1 mile and 2.6 million live within 50 miles; most of the latter live in or near Minneapolis-St. Paul. Airborne radionuclides are discharged from a 100-m-tall stack and a set of 3 vents atop the reactor building.

The annual release totals for the various categories of radionuclides compiled from semiannual reports by the operator to NRC in Table 1 show, in general, an increase in airborne releases during the first four years of operation, a decrease for the next three years and fairly uniform releases in 1977, 1978, and 1979. The lower and relatively stable release rates during the past three years can be attributed to better fuel cladding with lower leakage rates and installation of a gas treatment system that delays release of the effluent from the main condenser steam jet air ejector -- formerly the main source of gaseous radionuclides -- by approximately 450 hours (NS 80e).

The radionuclide composition of the airborne effluent in 1979 is given in Table 2 basically in the format specified in Regulatory Guide 1.21 (RS 74). Radioactive particulates are measured weekly on a filter, and gaseous radioiodine is measured at the same time on a charcoal cartridge placed behind the filter in the sampling line. Both samplers operate continuously in the stack and vent lines. Tritium values are obtained from silica gel moisture collectors that sample continuously and are analyzed bi-weekly for the H-3 concentration in water. Krypton and xenon values are not measured but are computed from continuous gross gamma-ray monitoring data in stack and vent lines, gamma-ray spectral analyses of monthly grab samples of gas at the main condenser steam jet air ejector, and inferences concerning sources of the gases in the stack and vents (NS 79). Carbon-14 releases were not measured; the value in Table 2 is the generic default value given by the NRC (SD 76).

The composition of airborne radionuclides differs among the several streams that reach the monitored discharge points, particularly with respect to the presence of short-lived noble gases. These streams, which are mostly continuous but include some periodic discharges during reactor startup and while the reactor is being repaired or refueled (NS 80a, NS 76), are shown in a companion report (MH 80), which also describes the waste treatment and monitoring systems for airborne effluents.

The "less than" notation in Tables 1 and 2 indicates that at least some samples were below the limits of detection. Hence, the values so identified may consist either of a sum of detection limits or a combination of measured releases and detection limits.

<u>Collective dose commitment within 50 miles</u>. The collective dose commitment was computed to be 1.5 person-rem/year to the total body, 3.1

person-rem/year to bone, and 3.0 person-rem/year to the thyroid as shown in Table 3. The total collective dose commitments for other organs listed in footnote 3 to Table 3 were almost identical to the total body dose because the critical radionuclides in all cases except the thyroid were H-3 and C-14 deposited internally after ingestion and inhalation. Ingestion and inhalation of radioiodine contributed to the thyroid dose.

The method used to compute these doses is described in the draft report made available by the operator (NS 80):

> "Source terms for 1979 were obtained from the two semiannual reports prepared by each plant during the year.
>
> Meteorological data from the Monticello and Prairie Island SEDAR instrumentation systems for the full year were obtained. NRC computer code XOQDOQ was used to calculate annual average values of X/Q and D/Q for the gaseous releases. NRC computer code GASPAR was used to calculate offsite and population doses due to gaseous releases."

The calculational models are described in Regulatory Guides 1.109 (SD 77) and 1.111 (SD 77a); the transfer, uptake, and dose parameters used are from Regulatory Guide 1.109. The dose commitment refers to the external radiation dose in 1979 plus the dose during fifty years due to radionuclide intake in 1979. Furthermore, the calculation of the dose commitment from radionuclides deposited on the ground and from ingested radionuclides that had followed the air-soil-vegetation pathway assumes accumulation of radionuclides in the soil for 15 years at the 1979 rate to approximate typical values during a 30-year operating period.

The calculations are based on the source terms given in Table 2 (except as indicated in footnote 3 to Table 2), meteorological data for 1979, and an estimated population in 1979 based on linear extrapolation from 1960 and 1970 census figures distributed among the radial sectors for 16 directions and 10 distances (every mile from 0 to 5, 5-10 and every 10 miles from 10 to 50). The elevations of the source terms of 100 m at the stack and 42.4 m at the vents were increased for the vertical release velocity in accord with Regulatory Guide 1.111; average production per unit area for vegetables, milk, and meat in Minnesota was applied to the 160 sectors; and the radionuclide concentration resulting from deposition and uptake was averaged to compute the radionuclide concentration of the food and milk ingested by all persons within 50 miles.

Dose commitment to maximum exposed individual. The annual dose at a dwelling 0.5 miles southwest of the station stack was 0.2 mrem to the total body as well as individual organs of a child and the highest dose was 0.3 mrem to the skin at a dwelling 0.8 miles SSE, as shown in Table 4. The main sources of exposure were external radiation from the short-lived noble gases in air and internal radiation from H-3, C-14, and I-131 in vegetables grown at the location and consumed by the persons living there. No dairy or meat animals were kept at the dwelling (NS 80). As indicated in footnote 2 to Table 4, the highest annual external radiation dose at the site boundary was 0.4 mrem.

The same procedures described above were used to compute the dose to maximum exposed persons. In addition (NS 80), "NRC computer code RABFIN was used to evaluate gamma air and whole body doses at the site boundary for Monticello stack release. RABFIN uses finite plume geometry and GASPAR assumes a semi-infinite cloud. For elevated releases, finite plume calculations generally are more conservative."

The maximum exposed person was selected by calculating doses at several locations where high dispersion factors X/Q in sec/m^3, and deposition factors, D/Q in m^{-2}, indicated that one or a combination of several of the six pathways listed in Table 3 would result in maximum exposure. The higher consumption and inhalation rates recommended by the NRC for maximum exposed individuals (Table E-5 in Regulatory Guide 1.109) were used in lieu of site-specific data, and it was not determined whether a child actually lived at the dwelling under consideration. No consideration was given to possible exposures due to foods from several locations, or to the amount of food actually grown near that dwelling. Doses to adults and teenagers were somewhat lower than the dose computed for the child (NS 80e).

Environmental radiological monitoring results. No elevated radiation or radionuclide levels attributable to station operation were found in any of the measurements summarized in Table 5 that check for possible contamination from airborne effluents at Monticello. The external radiation level of 54 mrem/year is identical near the station and at a distance within the standard deviation of 6 mrem/year due to fluctuations in natural cosmic and terrestrial radiation. The Cs-137 levels in milk, natural vegetation, and soil at nearby indicator and distant control locations are also identical within the temporal and spatial fluctuations in radionuclides due to fallout from tests of nuclear devices in the atmosphere. No control values are available for Cs-137 concentrations in airborne particulates, but the average gross beta values, which include Cs-137, were the same in indicator and control locations. The Sr-90 average concentrations in indicator and control locations were also identical within the indicated uncertainty. No other radionuclides were detected above the indicated lower limits of detection. The Sr-90 and Cs-137 values are attributed to fallout from the long series of tests of nuclear devices in the atmosphere, including the most recent test to contribute these radionuclides, conducted by China on December 14, 1978 (NS 80a).

The indicator samples are collected from permanent locations 0.5 to 5 miles distant from the plant, while control samples are obtained 9 to 12 miles distant. The dosimeters and airborne iodine and particulate collectors operate in place continuously. Collections are on a quarterly basis for the dosimeters and weekly for particulate and iodine collectors. Milk samples are collected monthly and all other samples, occasionally.

The locations of the nearest dwellings, gardens, and animals that are sources of milk or meat in all 16 directions within 5 miles of the station are identified for computing doses to maximally exposed persons (NS 80). A yearly summary of land use within 5 miles will be required according to technical specifications now being processed, but is not now available to indicate in detail the foods or other radionuclide transfer media that must be considered in computing radiation doses to persons (NS 80e).

2.2.2 Prairie Island Nuclear Generating Plant

Airborne releases. The Prairie Island Nuclear Generating Plant is also operated by the Northern States Power Company. It has two pressurized water reactors (PWR's) supplied by Westinghouse that each operate at a licensed power of 1650 megawatt thermal. The station is located in a valley on the west bank of the Mississippi River near the town of Red Wing, Minnesota, approximately 40 miles southeast of Minneapolis-St. Paul. According to the population estimate by the operator for 1980, 97 persons live within 1 mile and 2.1 million live within 50 miles; most of the latter live in or near Minneapolis-St. Paul and a majority of persons in the group within 50 miles is also within 50 miles of the Monticello Nuclear Generating Plant. Sectors from NNW eastward to ESE of the plant are in Wisconsin, across the Mississippi River. Airborne effluents from the plant are released at 8 vents located on the roofs of buildings.

The annual radionuclide release totals in several categories summarized in Table 6 from semiannual reports by the operator generally show fluctuations but no significant trends for the five years of operation. Exceptions are an increase in tritium and a decrease in radioactive particulate releases.

The composition of the combined radioactive releases at the 8 vents is shown in Table 7. The radioactive particulate and radioiodine values are based on continuous sampling and weekly analysis at 6 of these vents. The two main condenser steam jet air ejector vents are normally not sampled because little leakage from the primary into the secondary system is expected; they are sampled periodically when leakage occurs (NS 80e). The amounts of radioactive noble gases were computed from gross gamma-ray monitors at all 8 vents, gamma-ray spectral analysis of samples collected once weekly at each vent, and an assumed fresh fission product composition. The continuous monitors showed only occasional elevated levels above background radiation (NS 80e). The radioactive gas decay tank is discharged 3 to 6 times per year; samples are analyzed for photon-emitting radionuclides and H-3 while releases of particulate and radioiodine contents are monitored as part of the vent releases. Carbon-14 releases were not measured, hence the NRC generic default value is listed in Table 7 (SD 76a).

Most of the airborne radionuclide release is due to refueling and repair shutdowns, occasional incidents, and periodic discharges from the gas decay tank (NS 80e). The airborne discharge pathways and their monitoring and treatment systems are described in the companion report (MH 80).

Collective dose commitment within 50 miles. The collective dose commitment was computed to be approximately 8 person-rem/year to the total body and all organs but one of those listed in Table 8 (including footnote 4); the highest dose was 34 person-rem/year to bone. The only significant pathways were food and milk consumption and the significant radionuclides were H-3 and C-14.

The calculational model and parameters are those described in Section 2.2.1. The source terms in Table 7, data from the Prairie Island meteorological tower, and population data for the Prairie Island vicinity extrapolated linearly from 1960 and 1970, were used. Because the roof vents at the station are below maximum building height and are covered, release of airborne radionuclides was assumed to be at ground level in all calculations (NS 80e).

Dose commitment to maximum exposed individual. The dose commitment to a child at a dwelling 0.5 mile SSE of the plant was computed to be 7 mrem/year to the total body and 31 mrem/year to bone, the maximum exposed organ; doses to all other organs listed in Table 9 (see footnote 3) were also 7 mrem/year. This dose to the total body exceeded the station-originated external radiation dose at the site boundary. Table 9 shows that almost the entire dose is from C-14 in food. The dose from milk was not included because there was no dairy cow at this location; doses at other locations that included dairy cows were below this total. Doses to adults and teenagers were somewhat less than for the child. No consideration was given to the amounts of meat and vegetables actually grown for consumption and consumed at this location, whether a child lives at this dwelling, or the possibility of added exposure from drinking milk produced nearby (NS 80e).

The dose commitments to the maximum exposed individual shown in Table 9 are as high as they are because continuous C-14 releases at ground level are assumed in the calculation. The NRC calculational model (Regulatory Guide 1.109, equation C-8) takes the fractional equilibrium ratio -- the ratio of the total annual release time for C-14 to the total annual time during which photosynthesis occurs -- to be 1.0 and assumes that photosynthesis occurs during 4,400 hours per year.

The operator believes that C-14 is released at Prairie Island only on a few occasions by batch ventings (NS 80e). A second calculation, therefore, was performed by the operator in which the release time was taken to be 30 hours per year (NS 80f). The following different dose commitment values were found for the child at the same location, in mrem/year:

Pathway Radionuclide	Total Body	Bone	Thyroid
Plume			
Kr-87, Xe-133, Xe-135, Ar-41	8.9 E-2	8.9 E-2	8.9 E-2
Inhalation			
H-3	8.6 E-2	0.0 E+0	8.6 E-2
I-131	4.9 E-5	8.6 E-5	2.9 E-2
Other	4.0 E-6	3.7 E-5	1.1 E-3
Total	8.6 E-2	1.2 E-4	1.2 E-1
Vegetables			
H-3	4.5 E-1	0.0 E+0	4.5 E-1
C-14	3.7 E-2	1.8 E-1	3.7 E-2
I-131	1.5 E-4	2.6 E-4	8.5 E-2
Total	4.9 E-1	1.8 E-1	5.8 E-1
Meat			
H-3	2.7 E-2	0.0 E+0	2.7 E-2
C-14	5.7 E-3	2.9 E-2	5.7 E-3
I-131	1.4 E-5	2.5 E-5	8.3 E-3
Total	3.3 E-2	2.9 E-2	4.1 E-2
Total	7.0 E-1	3.0 E-1	8.3 E-1

The child at this location still remains the maximum exposed person after this change in calculational parameter, but the dose commitment in 1979 would be much lower.

Environmental radiological monitoring results. The TLD measurements showed no elevated external gamma radiation and the environmental samples contained no radionuclides attributed to Prairie Island (see Table 10). The only radionuclides found in these samples were Sr-90 and Cs-137 in milk and topsoil. The radionuclide levels in milk were slightly below those at Monticello and the levels in topsoil were approximately the same. No Cs-137 was detected in airborne particulates (at Monticello, 4 of 12 samples had detectable levels), possibly because the lower limit of detection was somewhat above that at Monticello.

The indicator samples are collected at permanently established locations 0.4 to 3 miles from the station, while control stations are 9 to 12 miles distant. The collection schedule is the same as at Monticello: continuous monitoring with quarterly readings for dosimeters, continuous monitoring with weekly analysis for airborne particulates and gaseous iodine, monthly sampling for milk, and sampling once or twice per year for other media. No potatoes or small animals were sampled at Prairie Island in 1979.

The locations of the nearest dwelling, garden, and meat- or milk-producing animals within 5 miles are determined in all 16 directions, as at Monticello, to permit computing the dose commitments to the most exposed persons (NS 80). In summer 1979, moreover, a detailed survey was conducted of meat-producing animals within 1 mile, milk cows within 5 miles, and milk goats within 5 miles (NS 80b). Some beef cattle were found within 1 mile of the plant and some milk goats, within 15 miles. There were no regular suppliers of goat's milk. Some samples of goat's milk were analyzed, but the results were not included in the annual report (NS 80b). A detailed land-use summary will be performed in accord with pending technical specifications (NS 80e).

2.3 Generic Dose Calculations

2.3.1 Radioactive discharges

The releases predicted for Monticello and Prairie Island by the operator on the basis of GALE codes developed by NRC (SD 76, SD 76a) and operating and waste treatment practices at these stations (NS 76, NS 76a) are shown in Table 11 except that the C-14 and Ar-41 values are taken directly from the NRC documents. By comparison with Tables 2 and 7, all measured radionuclide releases except H-3 at Monticello were well below these model predictions for assuring compliance with Appendix I. Tritium releases were an order of magnitude higher than predicted by the NRC model. Carbon-14 was not determined at either station, and Ar-41 was not determined at Monticello. Note in Tables 3, 4, 8, and 9 that inclusion of the generic default value for C-14 has a major impact on computed population doses.

The following radionuclides are known to be in reactor systems and should be considered as airborne sources of radiation doses offsite although they have not so far been included in the generic airborne radioactive effluent:

- Nitrogen-13 (9.96 m) is considered in reactor water and steam calculations (SD 76) and has been measured at a BWR gland seal condenser steam jet air ejector at a rate corresponding to a discharge of approximately 1,000 Ci/year (Bl 76).
- Alpha-emitting radionuclides were detected at both stations in airborne effluent as gross alpha activity (Tables 1 and 6) but not identified. In spent fuel, alpha activity would be distributed as approximately 95 percent Cm-242, 9 percent Pu-238, -239, and -240, and 6 percent Cm-244 (Fi 77).

- Fe-55 (2.7 y) is included in reactor- water calculations (SD 76, Sd 76a) and was found in airborne particulate releases at both BWR and PWR stations (Ka 74, Bl 76) at levels one to two orders of magnitude above Fe-59, which is considered in the generic airborne particulate source terms.
- Radionuclides with short half lives, such as Mo-99 (2.75 d) and Np-239 (2.35 d), and with very short half lives, such as I-132 (2.28 h) and I-134 (52.6 m), are included in reactor water calculations (SD 76, 76a) and were found in BWR airborne effluent (Bl 76, Pe 73, Pe 78).

The very short-lived radionuclides may contribute to nearby exposures from inhalation and the ground and, in the case of N-13, from air, while the longer-lived radionuclides may contribute to the ingestion and inhalation doses at greater distances. Effluent measurements and generic calculations should determine whether any of these radionuclides have dosimetric significance comparable to the radionuclides that are currently being considered.

2.3.2 Calculational models

Plume dispersion, deposition, and external radiation doses. Airborne dispersion and transfer are computed by NRC with the XOQDOQ code (Sa 77) which is described in Regulatory Guide 1.111 (SD 77a) as a constant mean wind direction model. The calculational model assumes normal (Gaussian) distribution of airborne gases or particles (except as limited by interception at ground surface); a compilation lists this and other computational codes for dispersion calculations (Ho 77).

The calculation provides the dispersion factor X/Q, by which the average airborne radionuclide release rate is multiplied to yield the concentration, X, in ground-level air averaged for sectors in sixteen directions as a function of distance from the source. The dispersion factor at a location depends on wind speed, wind direction, source elevation, distance, and atmospheric stability. The NRC model uses Pasquill-Gifford stability classes determined by temperature difference measured at two elevations, and has correction factors for the elevation of the source affected by the vertical velocity of discharges, and for mixing due to nearby elevated structures and building wakes. Other techniques for determining stability classes and other stability categories have also been applied (Sl 68, Li 79). The concentration of radionuclides in the plume is decreased as a function of distance to account for radioactive decay and deposition.

The data for these calculations at nuclear power stations are obtained at a nearby meteorological tower and are reduced to joint frequency distributions on an annual basis, to be used with annual values of Q, the radionuclide discharge. Because these calculations are for flat terrain, adjustments based on tracer studies at the site are desirable for other terrain.

The several plume models are based on extensive and still ongoing development and testing (Sl 68, Mi 79, Li 79, Te 78). In applying test results, distinctions must be made among important differences in study conditions: long periods (months to years) vs. brief periods (minutes to hours); multiple sampling locations vs. single sites; extensive meteorological instrumentation vs. single meteorological tower; detailed stability class categorization vs. use of temperature difference at two elevations; and nearby vs. distant measurements. For example, in the model applied to nuclear power plants by the NRC and most operators, including the operator of Monticello and Prairie Island, use of meteorological data from a single tower and stability categories defined by two temperature measurements would be expected to limit strict applicability of the model to the vicinity of the plant for annual averages.

In two detailed dispersion studies at nuclear facilities, the Gaussian plume model overpredicted tracer concentrations. At the Savannah River Plant, an extensively instrumented program for a 100-mile radius overpredicted by factors of 2-4 (Te 78), while at the Hanford facility, use of temperature difference overpredicted approximately 16-fold for an 8-mile radius (Mi 79). In a number of long-term studies, predictions were within a factor of 4 of measurements (Li 79) and this factor also applied to brief measurements near the station when atmospheric stability was carefully defined (Li 79, Ka 74, Bl 76). Less agreement of predicted with measured values is reported for greater distances and in complex terrain; on the other hand, some instances of very close agreement (within better than a factor of 2) have been reported (Li 79).

The NRC computer code also calculates deposition rates from the plume onto the ground. The deposition rate is the product of the release rate Q and the deposition factor D/Q, determined for the same sectors and distances as X/Q (SD 77a). This approach was applied only recently. Before issuance of Regulatory Guide 1.111, the deposition rate was computed by multiplying X/Q at the location of interest by the deposition velocity, v_d in m/s (Sl 68). Values of v_d in the range 10^{-3} to 10^{-1} m/s have usually been reported (Sl 68, Mi 78), the value depending on the form of the depositing material, meteorological conditions, and the surface. The NRC model and the factor v_d do not apply during precipitation.

A recent calculational comparison of the two models for release at 100-m height and atmospheric conditions at the Oak Ridge National Laboratory indicated that over a 100-km distance an average v_d of 0.007 m/s corresponded to D/Q per X/Q, but that the NRC model predicted higher deposition than the constant v_d by approximately a factor of 3 between 0.3 and 2 km, and lower deposition thereafter (Mi 79a). This reversal is an inherent consequence of early depletion of a plume.

The D/Q model also is awkward to use for radionuclides with several deposition velocities; for radioiodine, Regulatory Guide 1.109 recommends using fifty percent of the source term in order to account for hypoiodous, organic, and particulate forms, which have lower deposition rates on vegetation than molecular iodine (Ho 77a). The NRC further recommends a value for the fraction of deposited activity retained on crops by which the deposition rate is multiplied (SD 77); others have indicated a range of values for this factor (Br 79, Ho 79). Measured concentrations of I-131 on vegetation and in cows' milk at a nuclear power station in western Illinois showed agreement with predicted concentrations, however, when the various forms of radioiodine were considered with their appropriate deposition velocities (Vo 81).

The NRC computes the external radiation dose to the total body and the dose in air from the sector-averaged concentration of radioactive noble gases when the plume is at ground level by using the simple approximation that the radioactive cloud is an infinite hemisphere for gamma rays and an infinite sphere for beta particles (SD 77). Within several miles of an elevated source, this approximation does not apply, and a calculation based on a more complex integration of the gamma-ray flux from the radioactive cloud is used, as described in Regulatory Guide 1.109 (SD 77, Sl 68).

A number of dispersion studies have used measurements of gamma radiation instead of sampling radioactive or stable tracers, thus testing dose prediction at the same time. These studies show approximately the same 2- to 4-fold range in the ratio of predicted to measured values indicated above for tracer sampling (Mi 79, Ka 74, Bl 76). Thus, the additional factors for dose prediction apparently do not cause significant additional errors in prediction. The factors beyond flux integration used in dose prediction are the energy and decay fraction of the radiation emitted by the radionuclide under consideration, values which are known far more accurately than any environmental parameter. On the other hand, the relatively large volume from which gamma rays expose a selected location results in less variability than tracer sampling for brief periods under all but the most stable atmospheric conditions.

The recently computed radiation doses to organs immersed in a cloud of radionuclides (Ko 80) differ noticeably from the dose to the total body used in Tables 3, 4, 8 and 9 for all organs. The difference is small for radionuclides with relatively energetic gamma rays (e.g., 10-20 percent for Co-60 and Xe-138), but can be larger than a factor of two for radionuclides that emit low-energy gamma rays such as Xe-133. Use of the total body dose for all organs underestimates the dose to the skeleton and bone marrow and overestimates the dose to most other organs.

For computing the dose to the total body from radionuclides deposited on the ground, Regulatory Guide 1.109 provides a dose factor for a source distributed over a large area horizontally and with a vertical source distribution factor of approximately 0.2 cm^2/g. Other distributions would change the dose factors by as much as 3-fold, depending on the energy of the emitted gamma rays (NC 76). Measured doses from fallout radionuclides deposited on the ground have been used to check these calculations. Doses from deposited radionuclides due to airborne effluent at nuclear power stations apparently have not been detected.

Factors for terrestrial transfer, uptake by animals and humans, and dose by inhalation and ingestion. The NRC in Regulatory Guide 1.109 presents relatively simple equations for computing the transfer of radionuclides through the terrestrial food web to humans, and the annual radiation dose to humans at specified intake rates. The transfers are computed one step at a time. Generic default factors and values are listed for each item; they include such values as the transfer factor of radionuclides from soil to vegetation and from an animal's feed to meat and milk, average ingestion rates for humans and animals, the turnover rate of radionuclides on vegetation, the density of vegetation and amount of contaminated soil per unit area, and the fraction of the year that animals are exposed on pasture. Calculations of doses usually require a series of such equations. Doses received by various pathways and radionuclides are then summed for each organ. The most exposed person is selected by comparing doses calculated for various pathways and locations. The maximum exposure is then adjusted upward by using maximum instead of average ingestion rates (SD 77). The collective dose is obtained by summing the average dose to the population in each of the 160 sectors within 50 miles of the station, as defined for dispersion and deposition calculations.

The generic default factors in Regulatory Guide 1.109 were taken from recommended values (Ng 68, Ga 72) based on reviews of results from surveys, stable element concentrations, radioactive tracer studies, monitoring programs, and, in some cases, inferences from related data. Typically, data sets have ranges over an order of magnitude, but some soil-to-vegetation factors range over approximately five orders of magnitude (Ng 68, Ng 79, Br 79). Even such simply observed parameters as vegetation density and feed intake vary greatly due to widely different conditions throughout the United States, seasonal effects, and species differences. The NRC recommends use of site-specific parameters to eliminate errors from applying generic values (SD 77), but most station operators, including the operator of Monticello and Prairie Island, calculate doses with generic default values.

Recent reexaminations of transfer data have resulted in the recommended factors given in Tables 12 and 13 for the four listed elements in transfers within the food animal and from soil to vegetation, respectively. The NRC default values are listed for comparison. Factors such as the transfer from cows' feed to milk (Table 12) show relatively little disagreement among authors and with NRC default values (i.e., less that an order of magnitude); others, such as the transfer from soil to grass and leafy vegetables (Table 13), show great differences. The lower generic values selected by the NRC for soil-to-vegetation transfer are based on stable element ratios compared to the much higher values from tracer experiments (Br 79). Factors that differ from those in Regulatory Guide 1.109 have also been suggested for several other elements (Ng 79, Br 79) and could probably be found for every radionuclide that attracted sufficient interest to stimulate widespread studies and observations.

The wide ranges of parameter values and differences in recommended generic factors suggests the desirability of a quantitative selection principle beyond a "conservative estimate", and raises the potential of large predictive errors as the product of a chain of highly uncertain transfer factors. A better-defined selection of generic terms has been approached in three ways:

- Ng et al. at the Lawrence Livermore Laboratory (Ng 68) initially selected parameters leading to maximum doses in many pathways. With this procedure, pathways and radionuclides that do not present significant exposure potentials can immediately be eliminated from further consideration. Pathways and radionuclides that show significant doses by this procedure are subsequently analyzed with site-specific factors to identify important dose contributors and eliminate trivial ones.
- A group at the University of Heidelberg (Br 79) selected a "realistic value" and a "conservative value" at the upper error limit. The conservative value serves the same function as the above-cited maximum dose factor; the realistic value, however, is still not sufficiently defined.
- Hoffman et al. at the Oak Ridge National Laboratory (Ho 79) present all reported values in the form of a statistical distribution that approximately fits log-normal statistics in many cases, and normal statistics in a few. A median value (at the 50th percentile) and a value representing an extremely high factor (for example, the 99th percentile) are then reported.

Of these three approaches, the latter yields the most well-defined factors, although the population of reported values may not, of course, represent the actual range of conditions.

If all parameters in the chain of transfer calculations are either normally or log-normally distributed or can be approximated by such distributions, it becomes possible to combine associated standard deviation values appropriately to determine overall uncertainty (Ho 79). A sample calculation to relate the important dose to infant thyroids to the deposition rate of I-131 on pasture grass consumed by dairy cows showed a ratio in terms of mrem/year per pCi/m^2 day of 0.89 at the 50th percentile and 12 at the 99th percentile. Some generic values for component factors are well above the median values and others are well below them but the NRC generic default value of 15 mrem/year per pCi/m^2 day for the entire chain is remarkably conservative (Ho 79).

The dose conversion factors in Regulatory Guide 1.109 that relate annual inhalation and ingestion rates of each radionuclide to the annual dose commitment rate are based on biological half lives, transfer factors from GI tract and lungs to specific organs and tissues, organ and tissue characteristics, and radioactive decay characteristics selected by ICRP (Ho 77b). A series of reports by ICRP now being published (IC 79) changes some of these parameters, which are primarily from the 1959 report of ICRP Committee 2 (IC 59). A recently calculated ingestion dose factor in the thyroid for I-131 by infants at the 50th percentile of 1.1 x 10^{-2} mrem/pCi confirms the value in Regulatory Guide 1.109 of 1.39 x 10^{-2} mrem/pCi (Ho 79).

The dose conversion factors for adults used by the Heidelberg group for Wyhl are larger than the NRC values by a factor of 13 for Sr-90 in adult bone and by a factor of 40 for Cs-137 in the adult liver (Br 79, Co 80). The higher Cs-137 dose factor to the liver was not explained. The higher dose factor for Sr-90 in bone is due to the transfer factor from food to bone of 0.21 used by the Heidelberg group (Br 79), compared to 0.09 recommended by ICRP (IC 59) and 0.0225 used as the basis of Regulatory Guide 1.109 dose conversion factors (Ho 77b). The transfer factor of 0.21 was recommended by ICRP for all shorter-lived strontium radioisotopes (IC 59) and the Heidelberg group found no obvious reason why this higher factor should not apply to Sr-90. A more recent calculation of radionuclide intake limits (Ad 78) used a transfer factor from GI tract to blood of 0.3 and from blood to bone of 0.27 for all soluble strontium radionuclides (including Sr-90), for an overall transfer factor from food to bone of 0.081. Although the dose factor for Sr-90 in adult bone in Regulatory Guide 1.109 is 4-fold lower than that derived from the 1959 ICRP report, NRC staff (Co 80) cites even lower dose factors in support of the value in Regulatory Guide 1.109. The most recent recommendation by ICRP (IC 79) of the most restrictive Derived Air Concentration for workers of 60 Bq/m^3 (1.6 x 10^{-9} $\mu Ci/ml$) is similar to 1 x 10^{-9} $\mu Ci/ml$ in 10 CFR 20, Appendix B, Table 1, Column 1. For the other radionuclides of interest, the transfer factors on which Regulatory Guide 1.109 dose factors are based (Ho 77b) are the same as in the recent calculation of radionuclide intake limits (Ad 78): 0.3 for iodine from GI tract of thyroid and 1.0 for cesium from GI tract to the total body.

In summary, the generic calculational models are extremely useful for estimating the magnitude of the radiation dose based on effluent radionuclide measurements, and eliminating from further consideration the many radionuclides and pathways that contribute very little to the total dose. Such calculations have been remarkably accurate in a few instances, can generally be expected to predict doses within a factor of ten, and may be totally wrong if local conditions for dispersion and transfer are far different from generically applied ones. Local measurements are crucial for applying appropriate conditions and factors in the calculational model.

2.3.3 Environmental radiological monitoring

Guidelines for environmental radiological monitoring at nuclear power stations are presented in Regulatory Guides 4.1 and 4.8 to analyze important pathways for types and amounts of released radionuclides, identify radionuclide accumulation, consider the radiation hazard to plants and animals as well as humans, and establish correlations with amounts of released radionuclide (SD 75, SD 75a). These guidelines are based in part on recommendations for monitoring by the Environmental Protection Agency (RP 72). The sample type, sampling frequency, and detection sensitivity specifications listed in Tables 5 and 10 are consistent with the NRC Guides except that, while cows are on pasture, semi-monthly milk collection for I-131 analysis is specified instead of the reported monthly collection.

If the calculations that resulted in the doses to the most exposed individual listed in Tables 4 and 9 are correct, then the most important radionuclides --C-14 and H-3 in food grown near the stations -- have not been identified for routine monitoring. At the time these guidelines were developed, external radiation from radioactive noble gases in the plume and internal exposure to I-131 consumed in milk near BWR's were recognized as the most important exposure pathways. As indicated in Table 1, these two exposure sources have been reduced by approximately two orders of magnitude since 1975. This change is reflected in undetectably low levels of external radiation and I-131 in milk due to station effluents (Tables 5 and 10).

To assure that the monitoring program conforms to the indicated principles, the following are recommended:

- the program should be designed to consider the population and maximum doses calculated in Tables 3, 4, 8, and 9, monitoring the pathways and radionuclides that cause the major radiation doses. In the present instances, C-14 and H-3 in food and milk are the most important radionuclides;

- the land summary under way should be used to identify all potentially important pathways for sampling. The monitoring data in Tables 5 and 10 do not include meat from animals raised for human consumption, foods other than cabbage, corn, and potatoes, goat's milk, or fruit;
- monitoring should be able to distinguish incremental doses at Appendix I levels from natural background and fallout. This degree of accuracy may not be possible for the reported TLD measurements.

2.4 Consideration of Doses Calculated for the Stations

2.4.1 Radioactive discharges

The airborne noble gas releases at Monticello and Prairie Island were well below average among large commercial nuclear power stations at full operation in the United States according to the most recent tabulation for the year 1977 (De 79). Releases by 16 BWR plants ranged from 1.3×10^3 to 8.3×10^5 Ci with a geometric mean of approximately 3×10^4 Ci, compared to the release at Monticello of 6.87×10^3 Ci (Table 1). Some of the higher releases were due to incomplete installation of the required gas treatment systems. At 26 PWR stations, the range was from 2×10^1 to 4×10^4 Ci with a geometric mean of approximately 3×10^3, compared to 6.73×10^2 Ci at Prairie Island. The low releases at Monticello may have reflected in part the low power production relative to the other BWR's (11 terawatt-hours in 1977 compared to a range of 8 to 50 terawatt-hours). Power production at Prairie Island was above average for PWR's (25 terawatt-hours compared to a range of 4 to 40 terawatt-hours).

Because population radiation doses are computed entirely from radionuclide release data, it is imperative that discharges be reliably determined. The following items should be considered for improvement in the airborne effluent monitoring program, according to the data given in Section 2.2:

- Carbon-14, the major source of computed collective and maximum dose commitments to the population at Prairie Island and one of the major sources at Monticello, is not monitored in airborne effluent. An important consideration in dose calculations is the currently undetermined frequency of release as well as the amount.
- Tritium, another main contributor to the collective and maximum dose commitment, is measured only as tritiated water. Although the faction of H-3 in the form of hydrogen gas and organic gases measured at another BWR and PWR was small (Ka 74, Bl 76), this cannot be assumed to be the case without direct analysis. It is also not clear whether H-3 is monitored continuously at all 8 vents at Prairie Island.
- Kr-89 and Xe-138, the major sources of external exposure from the plume to persons near the station at Monticello, are not measured in effluents but inferred from periodic analyses of other radionuclides and an assumed noble gas radionuclide composition. Documentation to demonstrate the reliability of this inference is not presented in the semiannual reports.
- Xe-133 and Xe-135, the major sources of external exposure from the plume to persons near the station at Prairie Island, are determined from continuous gross gamma monitoring and once-weekly radionuclide analysis of a "grab sample". Documentation to demonstrate

the reliability of these calculations also is not presented in the semiannual reports.

- Combining lower limits of detection with measured values of particulate and iodine radionuclides (the practice at Monticello as indicated in Table 2) and reporting zero values for particulate and iodine radionuclides below the limits of detection (the practice at Prairie Island as indicted in Table 6) do not yield useful source terms for dose calculations. A better indication of doses would be provided by reporting the maximum possible value, which is the sum of measured values and lower limits of detection, and the minimum possible value, which is the sum of measured values only.
- Radionuclides that are currently not considered on a generic basis (see Section 2.3.1) should be added to the list of monitored radionuclides if predicted doses show them to be as important as radionuclides that are currently being measured. Conversely, radionuclides that are determined to be trivial contributors to the maximum and collective dose commitments on the basis of the calculational model with site-specific parameters can be removed from the monitoring program. It is not known whether additional measurements or data analysis to obtain the currently unavailable information would increase or decrease the computed radiation doses.
- All radionuclides that were measured should be used as source terms (see Table 2, footnote 3); questionable identification or values should be checked (see Table 7, footnote 3).

2.4.2 Calculational models

The operator's calculations. The following aspects of the dose calculations by the operator presented in Section 2.2 need further consideration:

- The fraction of the time during which C-14 is released must be determined to estimate the maximum and collective dose from C-14, the major source of radiation exposure according to these calculations.
- The maximum and collective dose calculations due to inhalation omit C-14. An estimate shows that C-14 contributes noticeably to the inhalation dose, although it is a small part of the total dose.
- The maximum dose calculation does not consider the possibility of persons at that location eating foods exposed to airborne effluent at other locations near the plant. Consumption of milk from cows grazing 2.2 miles SSE of Prairie Island and of milk and meat from animals grazing 3.8 miles WNW of Monticello would add the following respective dose commitments in mrem/yr to the child:

Organ	Prairie Island	Monticello
total body	1.4 E-1	9.8 E-3
bone	6.6 E-1	2.5 E-2
thyroid	1.6 E-1	2.5 E-2

The dose to an infant would be approximately twice as large. The values are from the operator's calculational program (NS 80).

- Doses to persons living more than 50 miles from the stations are not considered. Such doses can arise from the distribution of longer-lived gaseous radionuclides throughout the world, the passage of particulate and shorter-lived gaseous radionuclides for some distance beyond the 50-mile radius before deposition and decay, and the consumption of food grown within this radius at more distant locations. Information concerning food and milk productin within the 50-mile radius is not now available but should be supplied by the land-use survey; shipments into the area would decrease the dose commitment values computed in Tables 3 and 8, while shipments out would increase them. Approximately one-half of the radioactive material in the plume is deposited within the 50-mile circle according to station estimates of D/Q (NS 80), hence enlarging the area within which the collective dose commitment is computed might double the presented values, or add only a small fraction, depending on the location and number of persons and the distribution of the airborne radionuclides.

The world-wide collective dose commitment from the gases H-3, C-14, and Kr-85 computed by Atomic Energy Commission (AEC) and Environmental Protection Agency (EPA) staff was elevated for C-14 (Ka 76):

	AEC	EPA	Total body dose commitment
H-3	0.001	0.004	person-rem in 100 years per Ci releases (AEC) (in 40 years by EPA)
C-14	40	70	
Kr-85	0.0001	0.0005	

More recently, a dose of 0.02 person-rem per Ci in the year 2,000 was computed for H-3 (So79). Doses of 26 to 30 person-rem per Ci for a 100 year dose commitment (Fo 79) and of 540 person-rem per Ci for infinite time (more than 20,000 years) have been computed for C-14 (Ki 80). The collective dose commitment from C-14 per Ci decreases only slowly on a time scale small compared to its 5,700-year half life, and appears to be slightly less than 1 person-rem per Ci during the first year after release. Because of the complexity of the transfer of H-3 and C-14 through various media and the assumptions concerning dilution with stable elements and future population, these calculations are uncertain. They suggest, however, that the release of these radionuclides at the rates shown for 1979 in Tables 2 and 7 will result in a world-wide collective dose commitment almost entirely due to C-14 of approximately 10 person-rem per station in the year of discharge and of 5,000 person-rem at Monticello and 9,000 person-rem at Prairie Island for infinite time.

- Use of generic default values for all environmental parameters at both stations ignores the actual foods obtained nearby, the actual transfer factors from air and through intermediate media to these foods, and actual consumption rates. Wide deviations from some NRC default values have been noted (see Section 2.3.2) and unusual consumption patterns with regard to amounts or types of food are certainly possible. The current status can be improved once the anticipated land use survey has been performed (see Section 2.2) by applying site-specific values or their upper limits for transfer parameters to the identified possible sources of exposure. Some approaches to determining these parameters are given in Section 2.4.3.
- The calculations of long-term dose commitments need to include the doses due to higher radionuclide release rates before 1977.
- Pathways other than the six shown in Tables 3, 4, 8, and 9 should be considered to evaluate possible doses; currently unconsidered pathways include deposition on surface water, infiltration in ground water, and resuspension of dust. Doses due to these pathways are believed to be very small, but should be documented.

Calculations by others. A program at the Pacific Northwest Laboratory for computing collective dose commitments at all U.S. nuclear power stations showed a geometric mean value due to airborne release of 0.24 person-rem/year and a range from 0.001 to 120 person-rem/year for the year 1976 (Ba 79). Compared to this mean value, the computed collective dose commitments at Monticello and Prairie Island in 1979 (Table 3 and 8) are high. The 1976 survey did not include C-14 among airborne releases, however, and used simplifying assumptions that result in some differences compared to calculations performed for individual stations.

To provide a comparison with the collective dose commitment computed by the operator, D. A. Baker, Pacific Northwest Laboratory, has used this GASPAR-like program to calculate values based on 1977 releases from Monticello and Prairie Island (Ba 80). By special request, the generic default values for C-14 airborne releases were added to the source terms provided by the station operator. The values would be expected to differ from those in Tables 3 and 8 because the source term, population, and meteorological data are all different, the PNL program assumes effluent release at a height of 50 m, and estimates of the distribution of persons and of food grown near the stations are also characteristic of the program (Ba 79).

The resulting collective dose commitments in Table 14 for Monticello are between one-third and two-thirds of those computed by the operator (Table 3). These differences are not considered excessive in view of the differences in input data and program. The C-14 source term is the same for both programs; the annual discharge of noble gases and halogens was somewhat greater in 1977 than in 1979 but the discharge of H-3 was less (Table 1); the lower assumed discharge heights would increase the dose estimate; and the assumed population of 2.0 million compared to 2.6 million estimated by the operator would reduce the collective dose commitment.

The collective dose commitments in Table 15 for Prairie Island are approximately an order of magnitude below those calculated by the operator in Table 8. The arbitrary discharge height of 50 m would contribute significantly to this lower value relative to the ground level releases assumed by the operator. The amounts of released radionuclides and number of persons are similar for the two calculations. It has been suggested by operator staff (NS 80e) that some unreliable values in the 1974 meteorological data used in the PNL calculation may also contribute to underpredicting the dose. Hence, the values in Table 8 are considered more applicable.

Another calculation of collective dose commitment from airborne radionuclides was performed with the AIRDOS-EPA program (Mo 79) by M. T. Ryan at the Oak Ridge National Laboratory. The 1979 releases given in Table 7 (including C-14) and the 1979 meteorological data and estimates of population and food growth distribution within 50 miles of the plant by the operator were used. Discharge was assumed to be at ground level because the roof vents are below maximum building height and covered. The results summarized for Prairie Island in Table 16 (Ry 80) are considerably lower than in Table 8 but higher than in Table 15. The only radionuclides contributing noticeably to the population dose commitment are C-14, I-131, and H-3, in that order, and the only significant pathway is ingestion.

The different results obtained by the three calculational models indicate the extent to which different values of radionuclide transfer factors and intake dose factors affect the population dose commitment. Both the GASPAR and the AIRDOS-EPA programs have been used extensively. The most important difference in the results from the latter program is that both H-3 and C-14 are shown to have lesser impacts.

The AIRDOS-EPA model was also used to determine the population dose commitment to reproductive organs and to calculate values for the radionuclides Sr-89, Sr-90, Cs-134, Cs-137, and Pu-239, which were not detected in effluent (NS 79a). The dose commitment to the reproductive organs was 1.8 person-rem/yr on the basis of the higher values for either testes or ovaries. The summed dose commitment for a discharge of 1 x 10^{-5} Ci/yr each of Sr-89, Sr-90, Cs-134, and Cr-137 was calculated to be only 5 x 10^{-4} person-rem/yr, and an equal amount of Pu-239 would result in even lesser values, as indicated in footnote 6 to Table 16. It was assumed that any larger discharge of these radionuclides would have been detected (see Table 2).

The relatively high dose commitments to maximum exposed individuals predicted near the proposed Wyhl nuclear power plant by staff at the University of Heidelberg Department of Environmental Protection (Br 79) were examined to determine whether such high values could apply to the Monticello and Prairie Island stations. The elevated calculated doses relative to those usually encountered at U.S. nuclear power stations appear to be due mostly to assumed relatively high release rates, much larger transfer factors, and, in the case of the dose from radiocesium to the kidney, unusually high dose factors. At the two Minnesota plants, the measured or "less-than" source terms are so much lower than predicted for Wyhl that this difference alone would result in much lower doses than the highest computed for Wyhl:

			Prediction for Wyhl (Br 79)		Minnesota releases Ci/yr	
Food	Organ	Radio-nuclide	dose, mrem/yr	release, Ci/yr	Monticello	Prairie Island
wine	bone	Sr-90	570	1.0 E-2	1.65 E-4	<2 E-5
		Pu-239	165	2.0 E-4	<1. E-5	<7 E-8
beef	kidney	Cs-134	234	1.5 E-1	<5.72 E-5	<2 E-5
		Cs-137	5,057	4.0 E-1	<3.34 E-4	<2 E-5
milk	thyroid	I-131	59	3.0 E-1	<2.39 E-2	3.83 E-3

By all pathways at Wyhl, the calculated dose to bone from Sr-90 and Cs-137 is 5,300 mrem/year (3,700 mrem/yr from Sr-90 alone), the dose to the kidneys from Cs-134 and Cs-137 is 12,200 mrem/yr, the dose to the thyroid from I-131 and Cs-137 is 840 mrem/yr, and the dose to the total body from Sr-90 and Cs-137 is 820 mrem/yr (Co 80).

The releases at Monticello and Prairie Island given above are for 1979 from Tables 2 and 6. The "less than" values for Pu-239 are from gross alpha measurements in these tables; actual values would be expected to be about an order of magnitude less for summed Pu-238, -239, and -240 because of the expected presence of other alpha-particle emitters. The "less-than" values for Sr-90, Cs-134, and Cs-137 at Prairie Island are gross beta totals; actual values would also be expected to be lower.

Maximum dose commitments in Minnesota on the basis of this release rate comparison alone would be below 10 mrem/year for all but one of the radionuclides and organs that in the Wyhl estimate showed the highest annual doses. The exception is Sr-90 in bone by all pathways at Monticello, where the proportional dose would be 60 mrem/yr. The dispersion factor of 1.4×10^{-6} s/m^{3} at the maximally exposed location computed for the Wyhl plant (Br 79) is approximately one-half the factor at the corresponding location at Prairie Island, is equal to the factor for the vents at Monticello, and is well above the factor for the stack at Monticello (NS

80). Further indications that the doses in Minnesota are far below the estimates for Wyhl are provided by the radiological environmental measurements discussed in Section 2.4.3.

2.4.3 Environmental monitoring results

Environmental radiological monitoring is especially effective when used to estimate doses (or at least their upper limits) from measurements taken nearer the point of radiation exposure than the station vents and stacks, and to determine or confirm transport parameters for dose calculations. These applications are presented in this section although they are not in common use by station operators in Minnesota or elsewhere.

Current monitoring for the station operator. Dose commitments to the maximum exposed individual are computed in Table 17 from monitoring results (see Tables 5 and 10) combined with the indicated generic yearly intake values for the maximum individual and dose factors for ingestion and inhalation recommended by the NRC (SD 77). In accord with the conclusions by the station operator that the child is the most exposed individual (see Tables 4 and 9), values from Regulatory Guide 1.109 for the child were applied. The indicated "less-than" concentration values are the highest given in Tables 5 and 10; for the Sr-90 and Cs-137 concentrations in milk, an average value was used to represent the range that results from either combining real plus "less-than" values or using real values only. These ranges are relatively narrow and within the analytical uncertainty of measurement, e.g., the Cs-137 concentration in milk at Prairie Island lies between 1.7 and 3.4 pCi/l by this procedure and was taken to be 3 pCi/l in Table 17. The reported lower limit of detection was also used to compute the upper limit of radionuclide concentration or external radiation dose due to station operation where the measured values were attributed to natural activity (external radiation) or to fallout (Sr-90 and Cs-137 in milk and Sr-90 from gross beta activity in air). A lower limit of detection of 2 pCi/l was estimated for Sr-90 in milk in the absence of reported values.

The following observations concerning the dose to the most exposed individual are based on the data in Table 17:

- Radiation doses are relatively small at the measured or "less-than" values due to inhaling Sr-90, I-131, and Cs-137, and drinking I-131 and Cs-137 in milk.
- The upper limits of doses from station operation at the measured or "less-than" levels are several mrem/yr for external radiation, Cs-137 in all vegetables, and Sr-90 in milk.
- The natural radiation background of approximately 54 mrem/yr to the total body and the dose to bone from fallout Sr-90 by milk consumption of approximately 40 mrem/yr at Monticello and 20 mrem/yr at Prairie Island indicate the magnitude of the "background" doses under the assumed conditions and also the difficulty of determining any station-related doses in these pathways at levels of a few mrem/yr.
- Samples of meat and poultry from animals raised for consumption in the neighborhood should be analyzed for Sr-90 and Cs-137 to determine any contribution to the dose by these radionuclides.
- The major sources of dose commitment according to Tables 4 and 9 -- C-14 and H-3 -- were not considered in the environmental radiological monitoring program; if the calculations underlying these tables are correct, these radionuclides should be included in the analytical program. On the other hand, the "less-than" dose values

for Sr-90, I-131, and Cs-137 are consistent with the results given in Tables 4 and 9.

Integration of environmental radiological monitoring into the dose calculation program by the method demonstrated above is recommended. This activity is most effective with site-specific pathways and intake rates and with a sampling program matched to the amounts of materials consumed locally. Appropriate food consumption rates and dose factors must be applied. Note that intrusion of fallout radionuclides or fluctuations in the natural background can introduce considerable uncertainty.

Upper limits for Cs-137 transfer factors from soil to vegetation can be obtained from measured concentrations in these media (Tables 5 and 10) at the Monticello and Prairie Island stations. At average concentrations of 600 pCi/kg in soil at both locations, and of 100 pCi/kg wet weight at Monticello and less than 30 pCi/kg at Prairie Island in vegetation, the upper limits of the transfer factors are:

Monticello	0.17 kg soil/kg vegetation
Prairie Island	0.05 kg soil/kg vegetation

Actual values would be less because deposition from air contributes to Cs-137 in vegetation. If deposition from air contributed one-half or less of the Cs-137 in vegetation, these transfer factors would be higher than the generic value in Regulatory Guide 1.109 of 0.01 for vegetation relative to soil, (SD 77) but are considerably lower than the values listed in Table 13 that were selected for consideration of the Wyhl Station (Br 79).

Current monitoring by state and federal agencies. Environmental radiological monitoring for the station operator in one-half of the area near the Prairie Island station is checked by a sampling network operated on the northern and eastern side of the Mississippi River by the Wisconsin

Department of Health and Social Services (RP 78). The following samples check the airborne radionuclide pathway:

biweekly collection of air filters at 4 locations

monthly collection of milk at 2 of 3 locations also sampled by the operator

semiannual collection of soil at 8 locations

annual collection of vegetation at the same 8 locations

All samples are analyzed by gamma-ray spectroscopy. Air, soil, and vegetation are also measured for gross beta activity and milk is measured for I-131 and Sr-90 content by radiochemical analysis. Of the air filter locations, one is approximately 2 miles from the station and the other three are 9-13 miles distant. The two milk samples are collected at one of two nearby (2.5 mi NE and 3.5 mi NNE) farms and a more distant (11.4 miles) farm that also contribute samples to the operator's monitoring program. Of the eight soil and vegetation locations, three are 2-5 miles from the station and the others are 7-13 miles distant.

The available data for the first nine months in 1979 (He 80), summarized in Table 18, indicate that no differences were detected between the nearby and more distant samples. Similar "less-than" values applied to Cs-137 and all other photon-emitting radionuclides except for adjustments for rapid decay and fraction of gamma rays per disintegration. The reported values confirm the absence of the indicated radionuclides attributable to station operation.

The environmental radiological monitoring program by the operator is also checked by milk samples collected at some of the same farms in Minnesota by the Department of Health. In addition, three of eight state-wide samples are from the general vicinity of the two nuclear power plants.

During 1979, the milk samples summarized in Table 19 (Do 80) near Prairie Island averaged for Sr-90 approximately 3 pCi/l and for Cs-137 approximately 4 pCi/l, while I-131 was not detected (< 2 pCi/l). Levels of Sr-90 and Cs-137 throughout the state were similar to these, but values near Monticello were consistently higher. Milk samples from an indicator station in the immediate vicinity of the stations did not have significantly higher Sr-90 and Cs-137 levels than control samples, although the samples collected 2.3 mi ESE of Monticello averaged the highest Sr-90 concentration in the state. The levels of Sr-90 and Cs-137 confirmed those measured by the environmental monitoring contractor for the operator in samples collected from the same raw milk at two of the Monticello and one of the Prairie Island farms where this comparison was performed.

The Eastern Environmental Radiation Facility of EPA analyzes various samples from the Environmental Radiation Ambient Monitoring System, including pasteurized milk collected each month at 65 locations in the U.S., of which at least one is in each state. Samples are analyzed for I-131, Cs-137, and Ba-140 with 2-sigma deviations of 7-8 pCi/l. Strontium-89 and Sr-90 are usually analyzed in regional composites. The average Cs-137 concentration in milk from Minneapolis-St. Paul, the sole Minnesota sampling station, was 6 $\pm$ 3 pCi/l in 1979; I-131 and Ba-140 concentrations were all below the limits of detection except for an I-131 value of 8 pCi/l in April. Values for Sr-89 and Sr-90 of 0 and 3.8 pCi/l, respectively were found in a sample collected in July, 1979 (RP 79).

Special sampling was undertaken by EPA in December 1978 - January 1979 to look for fallout from the Chinese atmospheric nuclear test on December 14. The average Cs-137 concentration in three samples collected in Minneapolis-St. Paul on January 2-10 of 8 $\pm$ 4 pCi/l was not signifi cantly elevated. The maximum concentration in the system was 21 pCi/l at Tampa, FL, where Cs-137 levels are frequently highest. No short-lived I-131 and Ba-140 were detected above the 3-sigma level in any system samples. That fallout passed over the country was observed by elevated gross beta activity in airborne particles at several locations in the system, notably at Denver and Cheyenne where levels reached 1 pCi/m^3 on December 22 and 23. At Minneapolis, the gross beta activity in air remained at the current levels of 0.02 - 0.06 pCi/m^3 during the period of observation from December 18 to 29 (RP 79). These observations suggest that this most recent source of fallout to have a potential effect on radiological monitoring data in 1979 was not a significant contributor to radioactivity and radiation levels in Minnesota, although small increments could have been added due to special meteorological conditions locally.

Monitoring for the operator in earlier years at Monticello. An analysis (Tu 78) of data obtained from environmental radiological monitoring for the station operator in the period 1968-1977 at the Monticello station provides a means of evaluating the impact of releasing much higher levels of radioactive noble gases, iodine, and particulates than in 1979 (see Table 1). As indicated above and in Section 2.2.1, however, periodic intrusions of fallout from nuclear tests in the atmosphere by China and France complicate data interpretation. With the exception of external radiation, all measured levels were attributed to these tests or to natural radiation background.

During the period 1972-1976, a direct correlation was observed between the additional exposure to dosimeters within 0.4 - 4 miles of the plant, compared to more distant dosimeters (to 12 miles), and the total radioactive noble gas release rate (Tu 78). For dosimeters read every 4 weeks, the difference between the averaged exposures nearby and the averaged exposures at a distance was approximately 1 mR/4 weeks at a release rate of 40,000 uCi/sec, i.e., a ratio of 2.5×10^{-5} mR/4 weeks (3.2×10^{-4} mR/yr) per Ci/sec discharge at the stack. This average ratio is in reasonable agreement with the predicted ratio, taking the typical external gamma radiation dose factor for the period as 6×10^{-3} mrem/yr per pCi/m^3 (the dose factor for 0.8 MeV gamma range in an infinite hemisphere of air) and the average dispersion factor for stack release as approximately 4×10^{-8} sec/m^3 (NS 80) nearby:

$$0.6 \times 10^{4} \frac{\text{mrem/yr}}{\mu\text{Ci/m}^3} \times 4 \times 10^{-8} \frac{\text{sec}}{\text{m}^3} = 2.4 \times 10^{-4} \frac{\text{mrem/yr}}{\mu\text{Ci/sec}}$$

According to this factor, the release rate at the stack during 1979 of approximately 100 μCi/sec (see Table 2) would result in an average dose nearby of 2.4×10^{-2} mrem/yr. The additional dose from vent releases is approximately twice this value due to an 8 times higher dispersion factor and a 4-fold lower release rate. The sum of 7×10^{-2} mrem/yr to the total body by this rule-of-thumb calculation is consistent with the value of 8.6×10^{-2} mrem/yr to the most exposed person given in Table 4.

The other environmental radiation data compiled in the review are summarized as follows:

- Airborne particles were measured for gross beta activity only, hence no radionuclide concentrations are available; average concentrations near the station were not significantly higher than those at a distance. Airborne gaseous I-131 (collected on charcoal cartridges) was always below the lower detection limit of approximately 0.02 pCi/m^3.

- Milk was analyzed monthly for Sr-90, I-131, and Cs-137. Concentrations of Sr-90 ranged from 1 to 22 pCi/l, for I-131 from 0.1 to 210 pCi/l, and for Cs-137, from 3 to 40 pCi/l. Levels near the station were not significantly elevated and the pattern of increases and decreases was consistent with fallout as the source of elevated radionuclide levels.

- Food crops, mostly potatoes and corn, were obtained from nine locations near the plant; a control location 12 miles distant was added in 1976. The following average concentrations were determined between 1970 and 1977 in the nearby samples in pCi/kg wet weight:

	no. of samples in eight years	Sr-90	Cs-137
potatoes	17	7	7-9
corn	8	2	10-20
cabbage	2	-	10
soybeans	1	75	80

No I-131 was detected on any sample; the lower limit of detection was 0.01 pCi/g on cabbage and 0.02 pCi/g on soybeans. The Cs-137 concentrations are at the lower limits of detection given for the 1979 monitoring program in Tables 5 and 10. The Sr-90 levels are of interest because Sr-90 measurements apparently are no longer performed. At these Sr-90 concentrations, consumption of vegetables by persons would lead to approximately the same dose commitment from fallout as shown in Table 17 for milk consumption.

- Field vegetation sampled at several of five locations near the plant during the same years showed I-131 and Cs-137 levels from several pCi/g wet weight to undetectable (some below 0.01 pCi/g) levels. Other fallout radionuclides that emit gamma rays, such as Zr-95 and Ce-144, were also detected on occasion.

- Topsoil at 7 locations near the station was analyzed for Sr-90 and photon-emitting radionuclides. Average concentrations during the period 1970-1977 at all nearby locations were: Sr-90, 0.15 pCi/g (dry wt.) in 58 samples; Cs-137, 0.27 pCi/g in 89 samples. Control samples were obtained only in 1968. Some fallout radionuclides (Zr-95 and Ce-144) were also detected. Two samples in 1972 showed radionuclides attributable to the station (Cr-51, Co-60, and Cs-134) at concentrations of 0.01-0.02 pCi/g; no information is presented to indicate whether these observations were related to specific releases by the station or were analytical artifacts.
- No meat samples were collected.

The approximate transfer factor from soil to potatoes from the above-cited average values is 7/150=0.05 for Sr-90 and 8/270=0.02 for Cs-137. These factors are consistent with the LLL values in Table 13, although this average for data from different years and locations is approximate at best.

Environmental studies. Studies by the US EPA and NRC, in cooperation with the Minnesota Department of Health and the station operator, were performed at the Monticello station in 1973 to test the generic factors for the I-131 air-to-milk exposure pathway (We 74). The EPA also performed a study to test predictions of external radiation dose from the plume (Pa 76). These studies indicate the applicability of the calculational models to the Monticello site and also the magnitude of environmental levels measured at greater sensitivity than during routine monitoring.

The I-131 measurements at Monticello were performed from June 12 to July 5 while releases were in the range 0.05 - 0.3 μCi/sec at the stack and 0.0008 - 0.002 μCi/sec at the vents. The average chemical species distribution of discharged I-131 was as follows (We 74):

Species	Stack	Vents
particulate	0.04%	10.3%
molecular	21.7	29.3
hypoiodous	43.1	21.7
organic	35.2	38.7

Measurements in 1975 indicated even higher organic fractions (46-99 percent) at the stack (Pe 78).

Concentrations of I-131 in air measured for weekly periods at four locations between 0.8 and 1.7 miles distant from the station ranged from 5×10^{-4} to 5×10^{-3} pCi/m^3. No I-131 was detected (less than 3 pCi/m^2) on pasture vegetation 1.7 miles distant. The I-131 concentration in milk of cows grazing on the pasture averaged 0.25 pCi/l on the eight days when levels were detectable, and was below detection limits (usually 0.1 pCi/l) on 17 other occasions. The average for 25 days is between 0.08 and 0.16 pCi/l, depending on the concentration of I-131 below the limits of detection.

The average I-131 release rate in 1979 was 0.0008 μCi/sec (Table 1), hence the concentration of milk, if divided similarly between stack and vents and among chemical species, would be 160-fold less, i.e., approximately 0.001 pCi/l. This would lead to a dose commitment of 2×10^{-3} mrem/yr to the thyroid of a child for the maximum intake and dose factors in Regulatory Guide 1.109 (SD 77); if the I-131 were discharged mostly from the vents, the dose would be an order of magnitude larger. GASPAR code calculations by the operator predict doses higher by another order of magnitude, between 0.1 and 1 mrem/yr (NS 80).

The study of the station-to-milk I-131 pathway was terminated by the arrival of fresh fallout from atmospheric nuclear testing in China, which increased I-131 concentrations on grass to 30 - 160 pCi/m^3 (300 - 1,000 pCi/g dry weight), and in milk to 23-91 pCi/l. The elevated concentrations permitted calculations of a feed-to-milk I-131 transfer in cows of 0.012 day/liter ± 0.004 (1 standard deviation) (We 74), compared to the generic value in Regulatory Guide 1.109 of 0.006 day/liter.

In the EPA study from August 1973 to March 1974, pressurized ionization chambers measured the instantaneous external exposure rate within better than 1 μR/hr (Pa 76). The contribution to the exposure rate by radioactive gases in the plume from stack and vents is seen as rapid fluctuations in the recorded measurement above the natural background, and can thus be distinguished from the relatively constant natural background. Some corrections are necessary to account for brief variations in the natural background radiation during precipitation and gradual changes because of changes in soil moisture and snow cover. The detectors, at four locations 0.9 to 2.1 miles distant from the station, operated continuously for almost 7 months, and measurements were integrated for five intervals. The exposure due to the airborne radionuclides released at the station ranged from 7 to 34 mR for the entire study period.

The four measured net exposure rates due to airborne radionuclides from the station were compared with exposures predicted on the basis of noble gas release rates and meteorological data by means of four calculational programs. The source term was taken to be release rates reported by the operator for 6 radionuclides at the stack, which at that time was by far the main source of radioactive noble gases. The meteorological data were obtained from the station tower installation, corrected for observed periodic reversals of the wind-direction indicator by reference to data from the National Weather Service station at St. Cloud. The four models are all based on the assumption of Gaussian distribution of the plume, but differ in ways by which the cloud is assumed distributed throughout a sector, the way in which data are utilized, and the calculation of dose as a function of cloud distribution. The ratios of predicted to measured averages for the months of September, October, November, and December, and the standard deviation for each model, are (Pa 76):

AIREM	1.2 ± 0.5
AIREM-SI	1.3 ± 0.7
RRR	1.3 ± 0.6
ACRA	2.4 ± 1.2

The ratios are within the range discussed in Section 2.3.2, are relatively close to unity in the first three models, and are all above unity, i.e., they somewhat overpredict the exposure rate to persons nearby.

A locally applicable value of the Sr-90 feed-to-milk transfer was determined from November 1959 to June 1960 in a study at the Brainerd, Minn., milkshed because the Sr-90 concentrations in milk due to fallout at that time where higher by factors of 2 to 4 here and at Duluth than in the Minneapolis, Thief River Falls, Worthington, and Faribault milk sheds (Co 62). The Sr-90 concentrations in milk and all cattle feed at four dairy farms were measured in this study and averaged for each item. Based on the measured consumptions of hay, grain, and silage, the total intake of Sr-90 per cow was compared to the Sr-90 concentration in milk for average values during the entire 8-month period. The feed-to-milk factor averaged 2.3×10^{-3} day/l and ranged from 1.9×10^{-3} to 2.8×10^{-3} day/l at the four dairy farms. The generic factor for Sr-90 given in Regulatory Guide 1.109 of 8.0×10^{-4} day/l (SD 77) is considerably lower. More recently recommended values in Table 12 are within a factor of two or better of this measured value.

Applications for dose calculations. The environmental monitoring results for 1979 show no elevated levels of external radiation or radionuclides attributable to station operations at Monticello and Prairie Island. In some cases, the measurements assure dose commitments to the maximally exposed individual well below ALARA guidelines; in some instances, measurements at these levels are difficult to perform because of interferences by natural and fallout radiation; and in other instances, appropriate samples were not collected, the analytical method was insufficiently sensitive, or the radionuclides were not measured at all. In previous years at Monticello, noble gas radionuclides in the plume were detected by external radiation measurements and I-131 was measured in cows' milk; these measurements are no longer possible because release rates for these radionuclides have decreased by two orders of magnitude. Slightly elevated levels of photon-emitting radionuclides in topsoil attributed to airborne particulates from Monticello were measured on two occasions in 1972, but never since then.

Transfer factors that were determined in studies at or near Monticello or could be inferred from environmental monitoring data at the two stations were consistently within an order of magnitude of the NRC generic default values, and in some instances considerably closer. Better agreement was found with values recently compiled by Ng et al. (see Tables 12 and 13) (Ng 79). Somewhat higher levels of Sr-90 and Cs-137 in milk collected near Monticello compared to milk at Prairie Island and in other parts of Minnesota suggest either greater previous deposition in soil (probably from fallout in view of the low reported radioactive particulate emissions at Monticello during the entire period of operation) at that location or a larger transfer factor from soil to cattle feed; similar differences had been observed elsewhere in Minnesota during an early period of elevated fallout deposition (Co 62). Transfer factors have not been determined for some of the radionuclides that are the principal sources of dose commitment, and no information is available whether some of the pathways identified as major sources actually exist or provide the amounts of food intake used generically in the calculations.

The omissions in monitoring and transfer factor determinations indicated above can be rectified by planning the environmental monitoring program on the basis of the doses estimated from release rates by the calculational model. As important as the monitoring program are determinations of the identity and quantity of potential pathways at the sites.

2.5 Summary and Recommendations

Calculations by the operator (Tables 4 and 9) show that the radiation dose commitment for the maximum exposed individual near the Monticello Nuclear Generating Plant in 1979 was well within the Appendix I (ALARA) objectives, but that at the Prairie Island Nuclear Generating Plant it was near or above these values:

Type of dose	Computed dose commitment (Appendix I objectives), mrem/yr	
	Monticello	Prairie Island
total body	0.2 (5)	7 (2 x 5)
most exposed organ	0.3 (15) to skin	31 (2 x 15) to bone

The calculations were performed with the model and the generic default parameters given by NRC staff in Regulatory Guide 1.109. Almost the entire dose commitment at Prairie Island and much of the dose at Monticello is due to C-14, for which default release values were used because it was not measured in radioactive effluent. The station operator has performed a second calculation in which a brief period of C-14 release at Prairie

Island was used to reflect what the operator considers to be more realistic conditions than continuous release. In this calculation, the dose commitment is well below 1 mrem/yr to the total body and the most exposed organ.

The collective dose commitments within 50 miles of the stations computed by the operator (Tables 3 and 8) were:

Type of dose	Computed collective dose commitment, person-rem/yr	
	Monticello	Prairie Island
total body	1.5	7.9
most exposed organ (bone)	3.1	34

Most of the collective dose commitment at Prairie Island and much of it at Monticello are due to C-14 released at the generic default amounts. In addition, these releases of C-14 have been estimated to cause a worldwide collective dose commitment to the total body of approximately 10 person-rem/yr per station in the year of release and of 5,000 person-rem from Monticello and 9,000 person-rem from Prairie Island for the next 20,000 years. The collective dose commitments apply to overlapping populations of 2.6 million persons at Monticello and 2.1 million at Prairie Island, and to a world population of 4 billion increasing to 12 billion in 2075. These dose commitments are extremely small relative to the natural radiation background, to the extent that the average values of well below 0.2 mrem/yr per person near the plants are much smaller than the fluctuations in the natural background incurred by a person's normal movement.

The only other radionuclides that contributed noticeably to the maximum and collective dose commitments according to these calculations were H-3 to most organs and I-131 to the thyroid. These result in average values below 0.0005 mrem/yr per person near the plant. Because of the predominance of C-14 and H-3 in the calculated internal radiation doses, the indicated total body dose commitments can also be applied to individual organs and tissues, notably reproductive systems.

The greatest need at both stations, but especially at Prairie Island, is to measure the annual release of C-14 in airborne effluent and the length of time during which these releases occur. If discharges occur for a large fraction of the year at or above the indicated default values, C-14 measurements should be given primacy in the environmental monitoring program. Of next importance is upgrading effluent monitoring for tritium to assure complete coverage and inclusion of tritium measurements in those environmental samples for which detectable levels of tritium can be predicted. Application of the anticipated land-use surveys at the stations is necessary to quantify the types and amounts of foods grown in the vicinity so that any heretofore unconsidered pathways identified by the surveys may be included in the dose calculation program. If, on the other hand, the measurements of C-14 releases show small amounts discharged during brief periods, population and maximum dose commitments at both stations would be low and require little environmental monitoring for C-14.

No unduly high maximum or collective dose commitments were found by applying conventional calculational models to the radionuclides that are monitored by the operator in airborne effluent. Pathways considered by the operator appear appropriate for computing these doses and the calculational parameters that could be checked were of the same order of magnitude as transfer factors applied to the sites. Absence of elevated levels of I-131 or other radionuclides in milk is confirmed by state-operated monitoring networks. Other monitoring results are consistent with source-related calculations in that no elevated levels of external radiation, photon-emitting radionuclides, or Sr-90 were found. Radiological monitoring of the airborne effluent and the environment indicate that radionuclide releases to the two pathways that were formerly considered to be the main potential sources of population exposure -- short-lived noble gases in the plume and I-131 in milk -- have been abated to result in extremely small dose commitment at Monticello and Prairie Island. Furthermore, the most recent available comparisons show that radionuclide releases and resulting collective doses at the two stations were in the mid-range for U.S. stations.

Predicting the transport of radionuclides through the environment with a calculational model involves considerable uncertainty. This was demonstrated by use of 3 computer programs that differed in population dose commitments at Prairie Island by more than an order of magnitude, and by some widely different recommended transfer factors. Measurements at the points of exposure are needed to check values for which the upper range of predictions could result in significantly elevated dose commitments.

Although there is no reason to believe on the basis of available information that maximum and collective radiation dose commitments are either much lower or higher than computed by the operator, improvements in airborne release monitoring, dose calculations, and environmental radiological monitoring are recommended in order to develop greater accuracy as well as confidence in computing doses. An improved program requires that the operator:

(1) Measure at the points of discharge all radionuclides (as distinct from inferences or use of generic default values) that are estimated to be major contributors to the dose, and determine reliable "less-than" values for all other radionuclides that should be considered as potential contributors to the dose.

(2) Use transfer parameters specific to the site for radionuclides and pathways that are estimated to be major contributors to the dose, and make certain that radionuclides and pathways that have been determined to contribute negligibly to the dose are evaluated with transfer parameters that are at least as large as locally applicable ones.

(3) Relate the environmental program to the dose calculation program by including the major radionuclide and pathway contributors to the dose in routine monitoring and defining site-specific transfer parameters by special measurements. Detailed recommendations are given in Sections 2.3 and 2.4 for considering specific radionuclides.

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3. Health Effects from Radiation Exposure

3.1 Risks to the Public from Gaseous and Airborne Particulate Radionuclide Emissions at Nuclear Power Plants.

All forms of generation of electrical energy impose some risks to the public as individuals and collectively. In the case of the operation of nuclear power plants we are also interested in risks from other parts of the nuclear fuel cycle. In general, these distinct operations affect different groups of people and are usually not additive.

In all such technological undertakings it is necessary that we understand present and future impacts, measure or estimate the effects or their precursors, have established appropriate standards and criteria, and effectively control the technology within the regulatory framework. The goal is the protection of health and safety with careful and continuing attention paid to the philosophy of keeping any related risks as low as reasonably achievable (ALARA).

Certain of the potentially harmful effects from the gaseous and airborne particulate radionuclide releases from a nuclear power plant are believed to be an increased risk from various types of malignancies and genetic mutations introduced into the population. Models and procedures are available to calculate such health effects and to compare them with similar effects produced by comparable causes.

As with most complex scientific matters, our understanding of the details is never as good nor as complete as we would like. However, there is general agreement on the types of risk from ionizing radiation and many of their defining characteristics and surprisingly reasonable agreement on the magnitude of the factors used to estimate and calculate risk.

Several of the more obvious but extremely important difficulties in our detailed understanding of the somatic and genetic effects of ionizing radiation are the latent periods involved, the necessary reliance on statistical methods, and the fact that the effects we are concerned with are frequent occurrences in the populations of interest and are the result of a number of other unspecified manifestations.

The latent period is defined as the intervening time between the event of exposure and the advent of response. This response is usually a specified end point which is capable of being measured or manifested. A further complication is the fact that the latent periods of interest are on the order of years to a few decades.

Our problem with statistical methods has to do with trying to recognize and identify the one effect in many which appear to be the same. The only label we have on an effect may be the probability that it should have occurred. This is indeed an area of scientific conjecture, rationale, and opinion and one that must be guarded from non-scientific methods, unfounded speculation, and ill-warranted premises and conclusion.

This brings us to the reality that the events we are trying to document and predict are masked by being present in a large pool of similar effects. At the present time, we have absolutely no way to tag and thus identify the specific effect which has our "statistical parents."

Of particular value is the fact that for gaseous and airborne particulate radionuclide emissions from nuclear power plants under operational conditions we are dealing with well defined factors. These factors in many cases are directly measurable and thus quantitative information is available for evaluation. Another desirable feature is the general concensus that we are dealing with low-Linear Energy Transfer (low-LET) radiation (primarily low to moderate energy beta and gamma radiations), low doses of such radiation (on the order of a few millirem of dose equivalent for an individual in a year's exposure time), extremely low dose rates (receipt of these few millirem distributed throughout one year), and materials which we can sample and accurately measure (for example the concentrations of ^{3}H, ^{131}I, and ^{14}C in air and foodstuffs).

In discussing special technical terms we are guided by the general understanding within the field and the definitions used in the BEIR Report (BE 72). When it is recognized that there may not be general agreement on terminology, the definition of choice will be given at the point of discussion.

Major reactor accidents are not discussed in this text but carefully conceived and frequently rehearsed emergency plans must be in existence for each nuclear power plant in order to minimize serious consequences should the major accident occur in spite of a very low probability of its occurrence. Of course, in case of a nuclear power plant accident, the airborne radioactive releases could be much greater than the normal, routine releases. In the life of any plant, a number of minor radiation incidents can be expected; usually, the major portion of the airborne material in such incidents can be confined within the reactor building or other parts of the power plant system. The risk that a major accident will happen during the life of a nuclear power plant is very small but not zero.

In the recent reports of the reactor accident at the Three Mile Island (TMI) station, the BEIR Report (BE 72) was used as the basis for the health effects evaluation. This decision was made by the U.S. Nuclear Regulatory Commission, the U.S. Environmental Protection Agency, and the Department of Health, Education and Welfare which published the joint report (Ba 79). Information from another comprehensive report (UN 77) was used for comparison purposes and the authors called attention to certain disagreements with the referenced data.

The major points are that this selection focused on a particular set of parameters, established a standard of reference, and indicated the preference of several regulatory agencies for a body of information and data to use in the comprehensive evaluation of the health effects to individuals and population groups in the vicinity of the TMI nuclear power plant accident. The joint report (Ba 79) also pointed out that it was the understanding that the updated version of the BEIR Report (BE 80) would not be significantly different from the health effects estimates which it had derived using the earlier BEIR Report (BE 72).

It is instructive to review briefly the analysis performed on the TMI data and the primary conclusions reached in the impact of health effects on individuals and the population within 50 miles of TMI. The estimated collective dose within a 50-mile radius of TMI was estimated as 3,300 person-rem with the individual average dose equivalent calculated as 1.5 mrem. Also, the estimated maximum dose equivalent to an off-site individual was less than 100 mrem.

Using these data, the joint task group (Ba 79) projected less than one (0.7) fatal cancer over the remaining lifetime of the population within 50 miles and slightly less than two excess health effects, including all cancers and genetic ill health to future generations. These numbers are contrasted with the projected number of 325,000 fatal cancers expected from other causes, within the lifetime of the population. This latter number is based on the risk of cancer death as 0.15 (CS 79).

The derived risk used in the estimation of cancer fatalities is from the BEIR Report (BE 72) and amounts to 200 cancer deaths per 10^6 person-rem. This includes leukemia and all other fatal cancers. It is the geometric mean of the upper and lower bounds of the dose-to-health-risk conversion coefficient and when multiplied by the mean estimate of the population dose (3,300 person-rem) produces the central estimate of about 0.7 fatal cancers.

An estimate was also made by the joint committee (Ba 79) of the genewKc dfYevts for all future generations for the population within 50 miles of TMI. The central estimate was 0.7 which derives from an estimated risk of 200 per 10^6 person-rem taken from the BEIR Report (BE 72). It is the total risk and includes data for various types of genetic disorders.

Based on a similar analysis of less complete (earlier) data, the Kemeny Commission (KC 79) concluded: "On the basis of present scientific knowledge, the radiation doses received by the general population as a result of exposure to the radioactivity released during the accident were so small that there will be no detectable additional cases of cancer, developmental abnormalities, or generic ill-health as a consequence of the accident at TMI."

The pertinent conclusions of the Rogovin Report (RR 80) for health effects were expressed this way: "The effects on the population in the vicinity of Three Mile Island from radioactive releases measured during the accident, if any, will certainly be nonmeasurable and nondetectable." Also, "The effect of this total dose, averaged over the population in the site area, will be to produce between none and one additional fatal cancer, and between none and one and a half total (fatal and nonfatal) cancers, over the lifetime of the population. In comparison, approximately a half million cancers are expected to develop from all other sources during this same lifetime." This report also emphasizes the fact that the additional lifetime fatal cancer risk to the maximum exposed individual in the TMI area (about 100 mrem dose equivalent) would be approximately 1 in 10^5 compared to the normal risk of fatal cancer from all other sources of 1 in 7.

Thus far, the literature has had many articles dealing with errors, faults, and problems at TMI but none has appeared finding fault with the basic conclusions reached in the evaluation of projected health effects using the procedures and models briefly summarized here but covered in a comprehensive fashion in the references cited.

3.2 The Basis for Establishing Risk Estimates and a Brief Look at the Current Literature.

The joint committee (Ba 79) stated: "The health risks from low-level radiation are derived by assuming that the effects observed at high doses from high dose rates can be directly and linearly extrapolated to low doses delivered at very much lower dose rates. It is also assumed that there is no absolutely safe dose (or threshold) below which there is no health risk. These assumptions result in a linear, non-threshold, dose-rate-independent dose-effect relationship." This is simply put and the joint committee goes on to point out that several groups believe that this relationship overestimates the health risk from low-level beta and gamma radiation doses (IC 77, NC 75, and BE 72). Also, it is mentioned, without reference, that there are recent studies that suggest the risks may be underestimated. It should be noted that many studies indicate the possibilities of more or fewer effects compared to the risk estimates using the linear hypothesis and possible reasons for such variations.

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Pertinent comments from the BEIR Report (BE 72) are: "--- the linear hypothesis, which allows the mean tissue dose to be used as the appropriate measure of radiation exposure provides the only workable approach to numerical estimation of the risk in a population. Further, since there is no means at present of determining the value of the dose-effect slope in the low-dose region of interest, use of the linear extrapolation from data obtained at high doses and dose rates may be justified on pragmatic grounds as a basis for risk estimation."

The same concept is worded this way in a recent NCRP Report (NC 80): "The assumption of a linear, no-threshold dose-response relationship has generally been considered to provide a conservative approach to risk estimation for low dose and dose rate exposure, because the effect per unit dose for low-LET radiations has usually been observed in biology and medicine to decrease with decreasing dose and dose rate." This latter publication's title, "Influence of Dose and Its Distribution in Time on Dose-Response Relationships for Low-LET Radiations", is an apt description of the report's contents.

A brief and useful summary of this general area is contained in "Biological Effects of Low Levels of Radiation Exposure" by Casarett (Ca 78). Emphasis is placed on pertinent radiobiologic principles and theories and on considerations of risks at low radiation levels.

The NCRP Report (NC 80) provides an extensive review of the literature in this area and summarizes the reported views on both sides of the issue -- namely whether or not the linear, non-threshold, dose-rate-independent dose-effect relationship overestimates the risks or underestimates the risks at low levels and low dose rates of low-LET radiation. The studies reviewed involved various types of radiation exposures, different amounts, rates, and types of radiation, differing biological populations, and various numbers of subjects.

This will be a summary of the extensive review provided in (NC 80) and will focus on the studies which have dealt with human populations. However, there is a voluminous literature on related non-human subjects and on other human populations which is instructive to consider. For additional detail the reader is referred to the cited literature.

The Tri-state study, which was a population-based leukemia case-control investigation of the early 1960's (Gr 66 and Gi 72) has been used (Br 72, Br 77, Be 77, and Br 79) to support the belief that the linear hypothesis underestimates the risk coefficient. This conclusion and certain of the procedures used in the analyses have been criticized by several authors (Ma 72, Sm 73, La 77, Op 77, Ro 77, Bo 79, and NC 80).

Another study which has received wide publicity is the one of radiation workers by Mancuso et al. (Ma 77) which indicates an underestimation of the risk coefficient. Critics of this investigation have included a number of authors (An 78, Mo 78, Re 78, Gi 79, and Hu 79). Also, the same data have been analysed by other investigators (Gi 79 and Hu 79) who have applied different interpretations.

Other investigators have studied other occupational exposed groups (Na 78). This study examined workers and former workers at the Portsmouth Naval Shipyard and concluded that the linear hypothesis considerably underestimated the numbers of leukemias and cancers in the population of risk. This study has been reviewed and criticized by Reissland and Dolphin (Re 78), Hamilton (Ha 79), and the NCRP (NC 80). It has prompted a recently completed survey by Rinsky et al. (Ri 81) which indicates that there is no statistically acceptable evidence of an increasing mortality as a function of dose to ionizing radiation.

Two studies involving the effects of fallout from nuclear weapons tests conducted in Nevada have raised questions in interpretation of results. Lyons (Ly 79) has indicated an increase in leukemia incidence in children in Utah but has also pointed out a number of uncertainties in the data. The Center for Disease Control has reported (CD 79) preliminary results from its investigation of military personnel exposed at the Nevada Test Site during a particular nuclear atmospheric test in 1957. These results suggest an increased risk of leukemia, subject to modification as additional data are accumulated and analysed. Another continuing study of these effects of low-level radiation has recently been reported (Ca 80).

Other work has been suggestive of increased effects at low levels. This includes the reports by Brown (Br 76), Modan, et al. (Mo 77) and Morgan (Mo 75). The first two studies deal with data from human thyroid tumors whereas Morgan was concerned primarily with exposures from plutonium and other transuranium elements which emit high-LET radiation.

The NCRP Report (NC 80) presents a useful table (Table 10.1) which contains a summary of data on selected population studies on low-LET radiation and leukemia. It identifies the study population, its size, the periods of study, the estimated doses, other important features of the research, as well as certain aspects of the health risk. In many of these studies there has not been substantial scientific dispute regarding the findings.

There are also a number of fairly recent reports which argue that use of the linear hypothesis overestimates the risk and therefore suggest adjustments to compensate for these effects. For example, such compensating factors (factor of 3) were called for in estimation of genetic risks by the BEIR Report (BE 72) and by UNSCEAR (UN 77) and are now suggested (factors of 2 to 10) for production of tumors in man by the NCRP (NC 80). The latter recommendations are limited to a range rather than specific values and are defined as Dose Rate Effectiveness Factor, or DREF, "the factor by which linear interpolation from data obtained at high doses and dose rates overestimates the risk per unit absorbed dose of radiation delivered at very low doses and/or dose rates."

The NCRP Report (NC 80) concludes after its extensive review and evaluation of the available data that: "--there are some data and claims suggesting that the linear, no-threshold hypothesis may not be conservative and may even underestimate the effects at low doses and dose rates. (There is also a body of data, with varying degrees of statistical and methodological difficulties, that can be interpreted to show no effects at low doses or even a threshold.) While some are deserving of further investigation, the situations individually or collectively are not convincing enough to argue effectively against either the conservatism associated with the linear hypothesis or of the probable existence of DREF values for the human being."

3.3 Estimated Health Effects from Gaseous and Airborne Particulate Emissions from the Nuclear Power Plants at Monticello and Prairie Island.

The risk coefficients for health effects contained in the BEIR Report (BE 72) are used in this evaluation. This choice is made after carefully reviewing the extensive available literature, observing the use of such recommendations in evaluating the effects of the reactor accident at Three Mile Island, concluding that drastic changes in such risk coefficients will not be agreed upon by the scientific community in the near future, and taking note of the general magnitude of the projected effects.

Results of calculations of health effects for each of the nuclear power stations for the maximum exposed individual are presented in Table 20 whereas calculated data for the population within fifty miles of Monticello and Prairie Island are contained in Table 21. The whole body is considered for exposure as is the most exposed organ i.e., bone. In addition, genetic effects are given for the population within fifty miles of each nuclear power station in Table 21.

It is perhaps instructive to calculate such values and compare them with risks which are more familiar to most of us. On a relative basis these calculated health effects are extremely small; for example the normal risk of getting cancer is one in four and the normal risk of dying of cancer is about one in seven.

The report "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation" was published by the National Academy of Sciences in July 1980 (BE 80). It is familiarly known as the BEIR III Report and was prepared by the Committee on the Biological Effects of Ionizing Radiations of the Division of Medical Sciences, Assembly of Life Sciences, National Research Council, National Academy of Sciences.

It provides a thorough evaluation of the effects on population of exposure to low levels of various types of ionizing radiation. The scientific bases are presented upon which radiation protection standards may be based. The BEIR III Report largely confirms information and data presented in the BEIR II Report of 1972 and contains certain approaches to data interpretation and extrapolation which are less conservative than previous presentations.

A single extrapolation procedure to get from known data points (known effects of exposures to high measured doses of ionizing radiation) to the region of special concern, i.e. those low doses to which a human population might be exposed, is not given. Rather, a range of possible procedures is presented to accomplish this extrapolation. These are bounded by the linear model (the most conservative approach and the one utilized in BEIR II) and the quadratic model which produces a lower limit to the extrapolated data. The scientists' best judgement suggests use of a linear-quadratic model as the model of choice.

Major attention and focus of the BEIR III Report are with estimating the effects of low doses of low-LET ionizing radiation on population groups. These effects are primarily concerned with the long-term somatic and genetic risks to people. The principal late somatic effect of radiation exposure is cancer induction in a variety of organs and tissues. In addition, the current estimates of genetic effects, even though certain ones are calculated by a new method, are not notably different from the ones from the BEIR II Report.

For these reasons, the previously calculated effects for the exposures to the populations in the vicinity of Monticello and Prairie Island are in accord with those calculated using the BEIR III Report for guidance. The genetic effects remain essentially the same, whereas the projected somatic effects are bounded on the high side by the earlier calculated values while other models yield results that are lower by one to two orders of magnitude.

It should be noted that the expected exposures in the vicinity of Minnesota nuclear power stations are for low levels of low-LET radiation at extremely low-exposure rates. These latter rates, on an annual basis, when integrated for a lifetime will total on the order of one rad or less. The BEIR III Committee expressed the view that it did not know whether dose rates of the order of about 100 mrads per year are detrimental to man. The Committee points out that any somatic effects which might be produced at these dose rates would be masked by other factors, such as environmental factors, that produce health effects of the same types as those produced by ionizing radiation.

Thus, the BEIR III Committee has used a linear-quadratic dose-response model which it feels is consistent with the available epidemiologic and radiobiologic data in preference to the more extreme dose-response models, such as the linear and the pure quadratic. The presented results predicted by use of the linear response model, are most conservative and predict health effects about twice as high as those predicted from use of the linear-quadratic model for very low doses and considerably higher (one to two orders of magnitude) than the quadratic model under similar circumstances.

A summary of the significant conclusions of the BEIR III Report on the carcinogenic effects of low-levels of ionizing radiation has recently been published (We 80). This paper evaluates and discusses the primary findings with major emphasis on the cancer risks incurred by adult populations. These types of risks are the major concern in the area of health effects from low levels of low-LET radiation. In addition, skepticism is expressed regarding recent claims of increased cancer incidence in limited populations exposed to low doses of ionizing radiation on the order of one RAD.

It is anticipated that the results of the new calculations of the Japanese dosimetry data and the related impacts will be soon published in the open literature for scrutiny and analysis by the scientific community. Thus far, several papers have been given at technical meetings and letters of comment have appeared in such journals as Science. Several articles are currently scheduled for publication in Health Physics. It is not known what effects, if any, these results will have on our interpretation of biological effects on humans from exposures to gamma radiation.

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4. Tables

Table 1

Airborne Effluent Totals from the Monticello Nuclear Generating Plant, Curie/year

Year	Total noble gases	Tritium	I-131	Total halogens	Total particulates	Gross alpha	Reference
1971	7.60 E+4	-	3.60 E-2	-	note #5	-	De 79
1972	7.51 E+5	-	5.76 E-1	4.00 E+0	1.25 E-2	-	RO 73
1973	8.70 E+5	-	1.20 E+0	6.5 E+0	8.7 E-3	-	OE 75
1974	1.49 E+6	-	5.63 E+0	2.88 E+1	4.12 E-1	-	MI 76
1975	1.55 E+5	6.58 E+1	3.54 E+0	1.52 E+1	6.73 E-1	-	MI 77
1976	1.14 E+4	7.69 E+1	1.21 E-1	1.02 E+0	<5.02 E-2	-	De 78
1977	6.87 E+3	1.39 E+2	6.52 E-2	5.36 E-1	1.99 E-2	-	De 79
1978	6.42 E+3	2.36 E+2	4.12 E-2	1.54 E-1	1.37 E-2	7.38 E-6	NS 78
1979	4.03 E+3	2.20 E+2	2.39 E-2	<2.79 E-1	<1.00 E-2	1.14 E-5	NS 79

Notes:
1. Station initial criticality occurred on December 10, 1970.
2. For composition of noble gases in 1979, see Table 2.
3. Total halogens consist of I-131, I-133, and I-135.
4. Total particulates include only radionuclides with half lives longer than 8 days.
5. I-131 value in 1971 includes total particulates.
6. Notation 7.60 E+4 means 7.60×10^{4} or 76,000;
   3.60 E-2 means 3.60×10^{-2} or 0.036.

Table 2

Airborne Radionuclides Discharged at Monticello in 1979, Curie/year

Radionuclide	Half-life	Release Rate		
Gases		Stack	Reactor Bldg. Vent	Total
H-3	12.3y	6.12 E+0	2.14 E+2	2.20 E+2
C-14	5730y	9.50 E+0	-	9.50 E+0
Kr-83m	1.86h	7.89 E+0	2.15 E+0	1.00 E+1
Kr-85	10.7y	2.02 E+1	4.11 E-3	2.02 E+1
Kr-85m	4.48h	6.61 E+0	1.80 E+0	8.41 E+0
Kr-87	76.3m	3.96 E+1	1.08 E+1	5.04 E+1
Kr-88	2.84h	2.21 E+1	6.04 E+0	2.81 E+1
Kr-89	3.17m	7.69 E+2	2.10 E+2	9.79 E+2
Kr-90	32.3s	2.61 E+1	7.11 E+0	3.32 E+1
Xe-131m	11.9d	1.95 E+0	1.29 E-3	1.95 E+0
Xe-133	5.24d	2.82 E+2	7.75 E-1	2.83 E+2
Xe-133m	2.19d	6.26 E-1	3.65 E-2	6.62 E-1
Xe-135	9.09h	4.44 E+1	1.20 E+1	5.64 E+1
Xe-135m	15.3m	5.89 E+1	1.61 E+1	7.50 E+1
Xe-137	3.83m	1.01 E+3	2.74 E+2	1.28 E+3
Xe-138	14.2m	8.78 E+2	2.37 E+2	1.12 E+3
Xe-139	39.7s	7.77 E+1	2.12 E+1	9.89 E+1
Iodine and Particulates				
I-131	8.06d	<1.75 E-2	<6.41 E-3	<2.39 E-2
I-133	20.8h	<6.14 E-2	<3.12 E-2	<9.26 E-2
I-135	6.61h	<5.19 E-2	<1.11 E-1	<1.63 E-1
Cr-51	27.7d	<3.03 E-5	<5.70 E-4	<6.00 E-4
Mn-54	313.d	<7.00 E-6	<1.63 E-5	<2.33 E-5
Co-57	271.d	<1.71 E-6	<5.43 E-6	<7.14 E-6
Co-58	70.8d	<4.23 E-6	<1.05 E-5	<1.47 E-5
Fe-59	44.6d	<9.63 E-6	<2.23 E-4	<3.19 E-5
Co-60	5.26y	<6.95 E-6	<4.02 E-4	<4.09 E-4
Zn-65	244.d	<9.79 E-6	<2.37 E-4	<2.47 E-4
Sr-89	50.5d	1.80 E-3	1.14 E-4	1.91 E-3
Sr-90	28.5y	1.35 E-4	3.05 E-5	1.65 E-4
Zr-95	64.0d	<6.87 E-6	<1.63 E-5	<2.32 E-5
Nb-95	35.2d	<3.89 E-6	<1.00 E-5	<1.39 E-5
Ru-103	39.4d	<3.52 E-6	<8.99 E-6	<1.25 E-5
Sb-124	60.2d	<7.44 E-6	<1.66 E-5	<2.40 E-5
Sb-126	12.4d	<4.90 E-6	<1.08 E-5	<1.57 E-5
Cs-134	2.06y	<7.22 E-6	<5.00 E-5	<5.72 E-5
Cs-136	13.1d	<7.92 E-6	<1.84 E-5	<2.63 E-5
Cs-137	30.2y	6.83 E-5	<2.66 E-4	<3.34 E-4
Ba-140	12.8d	4.52 E-3	1.41 E-3	5.93 E-3
Ce-141	32.5d	<5.30 E-6	<9.79 E-6	<1.51 E-5
Ce-144	284.d	<8.89 E-5	<4.16 E-5	<1.30 E-4
Nd-147	11.1d	<1.02 E-5	<3.13 E-5	<4.15 E-5
alpha		1.03 E-6	1.04 E-5	1.14 E-5

Notes:
1. Values are from NS 79.
2. C-14 was not measured but is a NRC generic default value (SD 76).
3. Values for Kr-90, Xe-138, I-135, Co-57, Nb-95, Ru-103, Sb-126, and Nd-147 were not included as source terms in dose calculations.
4. The following noble gas values were calculated, not measured (NS 79): Kr-83m, Kr-85, Kr-89, Kr-90, Xe-131m, Xe-133m, Xe-135m, Xe-137, Xe-138 and Xe-139.

Table 3

Collective Dose Commitment within 50 miles of the Monticello Nuclear Generating Plant in 1979, Computed by the Operator, Person-rem/year

Pathway/Radionuclides	Total Body	Bone	Thyroid
By Pathway			
Plume	3.6 E-2 (2.3%)	3.6 E-2 (1.2%)	3.6 E-2 (1.2%)
Ground	1.0 E-2 (0.7%)	1.0 E-2 (0.3%)	1.0 E-2 (0.3%)
Inhalation	2.2 E-1 (14.0%)	5.7 E-3 (0.2%)	3.8 E-1 (12.6%)
Vegetables	8.0 E-1 (52.3%)	1.8 E+0 (57.4%)	1.6 E+0 (52.1%)
Cows' milk	3.1 E-1 (20.0%)	7.5 E-1 (24.3%)	8.3 E-1 (27.7%)
Meat	1.6 E-1 (10.7%)	5.2 E-1 (16.6%)	1.8 E-1 (6.1%)
Total	1.5 E+0	3.1 E+0	3.0 E+0
By Radionuclide			
H-3	8.7 E-1 (56.9%)	0.0 E+0 (0.0%)	8.7 E-1 (29.1%)
C-14	5.9 E-1 (38.3%)	2.9 E+0 (94.6%)	5.9 E-1 (19.6%)
Xe and Kr	3.5 E-2 (2.3%)	3.5 E-2 (1.1%)	3.5 E-2 (1.2%)
I-131	2.6 E-3 (0.2%)	3.7 E-3 (0.1%)	1.4 E+0 (47.7%)
I-133	1.8 E-4 (0.0%)	3.1 E-4 (0.0%)	6.3 E-2 (2.1%)
Sr-90	2.0 E-2 (1.3%)	8.3 E-2 (2.7%)	0.0 E+0 (0.0%)
Other particulates	1.5 E-2 (1.0%)	4.4 E-2 (1.4%)	9.9 E-3 (0.3%)
Total	1.5 E+0	3.1 E+0	3.0 E+0

Notes:
1. Xe and Kr consist of Kr-83m, Kr-85, Kr-85m, Kr-87, Kr-88, Kr-89, Xe-131m, Xe-133m, Xe-135, Xe-135m, Xe-137, and Xe-138; among these, over 90 percent of the dose is contributed by Kr-87, Kr-88, Xe-133, Xe-135, and Xe-138.
2. Other particulates consist of Cr-51, Mn-54, Co-58, Fe-59, Co-60, Zn-65, Sr-89, Zr-95, Sb-124, Cs-134, Cs-136, Cs-137, Ba-140, Ce-141, and Ce-144; among these, over 90 percent of the total body and thyroid doses are due to Co-60 plus Cs-137, and of the bone dose, due to Co-60, Sr-89, and Cs-137.
3. Doses to the GI tract, liver, kidney, lung, and skin are almost identical to the total body dose, although the individual pathway and radionuclide contributions differ slightly.
4. Data are from reference NS 80; estimated population is 2.6 million.

Table 4

Dose Commitment to Most Exposed Individuals Near the Monticello Nuclear Generating Plant in 1979, Computed by the Operator, mrem/yr

PATHWAY	RADIONUCLIDE	TOTAL BODY	BONE	THYROID
Plume	Kr-89 and Xe-138	7.6 E-2 (88.4%)	7.6 E-2 (88.4%)	7.6 E-2 (88.4%)
	Other Xe and Kr	9.9 E-3 (11.6%)	9.9 E-3 (11.6%)	9.9 E-3 (11.6%)
	Total	8.6 E-2	8.6 E-2	8.6 E-2
Ground	Co-60	2.5 E-3 (70.2%)	2.5 E-3 (70.2%)	2.5 E-3 (70.2%)
	Cs-137	8.3 E-4 (23.4%)	8.3 E-4 (23.4%)	8.3 E-4 (23.4%)
	Other particulates	2.2 E-4 (6.4%)	2.2 E-4 (6.4%)	2.2 E-4 (6.4%)
	Total	3.6 E-3	3.6 E-3	3.6 E-3
Inhalation	H-3	7.7 E-3 (99.7%)	0.0 E+0 (0.0%)	7.7 E-3 (50.4%)
	Sr-90	7.0 E-6 (0.1%)	1.1 E-4 (67.5%)	0.0 E+0 (0.0%)
	I-131	6.0 E-6 (0.1%)	1.1 E-5 (6.5%)	3.6 E-3 (23.4%)
	I-133	8.0 E-6 (0.1%)	1.7 E-5 (10.6%)	4.0 E-3 (26.2%)
	Other	3.0 E-6 (0.0%)	2.5 E-5 (15.4%)	0.0 E+0 (0.0%)
	Total	7.7 E-3	1.6 E-4	1.5 E-2
Vegetables	H-3	4.1 E-2 (73.0%)	0.0 E+0 (0.0%)	4.1 E-2 (45.2%)
	C-14	8.3 E-3 (14.9%)	4.2 E-2 (57.4%)	8.3 E-3 (9.2%)
	Sr-90	5.9 E-3 (10.6%)	2.3 E-2 (32.3%)	0.0 E+0 (0.0%)
	I-131	6.6 E-5 (0.1%)	1.2 E-4 (0.2%)	3.8 E-2 (42.6%)
	Other	7.5 E-4 (1.4%)	7.3 E-3 (10.1%)	2.6 E-3 (3.0%)
	Total	5.6 E-2	7.2 E-2	9.0 E-2
Cow's Milk			NONE	
Meat			NONE	
TOTAL		1.5 E-1	1.6 E-1	1.9 E-1

Table 4 (continued)

NOTES:

1. Location is 0.50 mi. SW of plant, at dwelling with vegetable garden but no meat or dairy animals.

2. The highest annual off-site air doses were 0.6 mrad from gamma rays and 0.5 mrad from beta particles; the highest annual whole-body gamma-ray dose at the site boundary was 0.4 mrem; the highest dose to the skin at a nearby dwelling was 0.3 mrem at 0.8 miles SSE.

3. Calculated total doses to the GI tract, liver, kidney, lung, and skin are similar to the total body dose.

4. The calculated maximum dose is to the child; doses to the adult and teenager are less.

Table 5

Environmental Radiological Monitoring Results Pertaining to Airborne Effluent
at the Monticello Nuclear Generating Plant in 1979

SAMPLE TYPE (units)	TYPE AND NUMBER OF ANALYSES[a]		LLD[b]	INDICATOR LOCATIONS, MEAN (F)[c] AND RANGE	CONTROL LOCATIONS, MEAN (F) AND RANGE
TLD (mrem/91 days)	Gamma	7-28	3.0	13.8 (20/20) (10.6-15.5)	13.4 (8/8) (11.4-14.5)
Airborne Particulates (pCi/m^3)	GB	7-437	0.001	0.040 (315/315) (0.011-0.095)	0.040 (122/122) (0.013-0.130)
Airborne Iodine (pCi/m^3)	I-131	3-155	0.02[d]	LLD	LLD
Air Particulates monthly composite of all locations (pCi/m^3)	GS	12		(12)	(0)
	Zr-95		0.001	LLD	NONE
	Cs-137		0.0006	0.0016 (4/12) (0.0014-0018)	NONE
	Ce-144		0.003	LLD	NONE
Milk (pCi/1)	I-131	5-60	0.25	LLD	LLD
	Sr-89	2-24	3.4	LLD	LLD
	Sr-90	2-24		6.1 (12/12) (5.1-7.6)	8.0(12/12) (5.7-10.2)
	GS	2-24			
	Cs-137		2.7	5.4 (7/12) (3.4-9.9)	6.7 (10/12) (2.7-12.6)
Crops - cabbage (pCi/g wet)	I-131	2-2	0.005	LLD(1)	LLD(1)

Table 5 (continued)

SAMPE TYPE (units)	TYPE AND NUMBER OF ANALYSES[a]		LLD[b]	INDICATOR LOCATIONS, MEAN (F)[c] AND RANGE	CONTROL LOCATIONS, MEAN (F) AND RANGE
Crops - corn (pCi/g wet)	GS	2-2		(1)	(1)
	Zr-95		0.038	LLD	LLD
	Cs-137		0.017	LLD	LLD
	Ce-144		0.11	LLD	LLD
Crops-potatoes (pCi/g wet)	GS	2-2		(1)	(1)
	Zr-95		0.045	LLD	LLD
	Cs-137		0.011	LLD	LLD
	Ce-144		0.069	LLD	LLD
Small Game Animals - flesh (pCi/g wet)	GS	2-4		(2)	(2)
	Zr-95		0.06	LLD	LLD
	Cs-137		0.03	LLD	LLD
	Ce-144		0.2	LLD	LLD
Small Game Animals - liver (pCi/g wet)	GS	2-4		(2)	(2)
	Zr-95		0.14	LLD	LLD
	Cs-137		0.09	LLD	LLD
	Ce-144		0.24	LLD	LLD
Natural Vegetation (pCi/g wet)	GS	3-6		(4)	(2)
	Zr-95		0.04	LLD	LLD
	I-131		0.06	LLD	LLD
	Cs-137		0.02	0.15 (2/4) (0.10-0.20)	0.14 (2/2) (0.10-0.18)
	Ce-144		0.33	LLD	LLD
Topsoil (pCi/g dry)	Sr-90	12-12		0.18 (10/10) (0.06-0.32)	0.18 (2/2) (0.12-0.24)
	GS	12-12			
	Zr-95		0.06	LLD	LLD
	Cs-137		0.1	0.59 (10/10) (0.24-0.85)	0.57 (2/2) (0.37-0.76)
	Ce-144		0.17	LLD	LLD

Table 5 (continued)

NOTES: 1. a. GB = gross beta; GS = gamma scan; numbers show number of locations-number of samples.

b. LLD = lower limit of detection based on 3 sigma error for background sample.

c. Mean and range based upon detectable measurements only. Fraction of detectable measurements at specified location is indicated in parentheses (F); the second set of parentheses contains the range.

2. Data are from NS 80a.

Table 6

Airborne Effluent Totals From the Prairie Island I and II
Nuclear Generating Plant, Curie/year

YEAR	TOTAL NOBLE GASES	TRITIUM	I-131	TOTAL HALOGENS	TOTAL PARTICULATES	GROSS ALPHA	REFERENCE
1975	2.17 E+3	1.01 E+1	1.84 E-2	2.10 E-2	3.60 E-3	-	MI 77
1976	<1.74 E+3	3.31 E+1	1.11 E-2	2.45 E-2	<2.27 E-4	-	De 78
1977	6.73 E+2	8.75 E+1	6.46 E-3	<8.07 E-3	1.10 E-3	-	De 79
1978	1.26 E+3	1.43 E+2	8.58 E-4	<1.51 E-3	3.80 E-5	2.51 E-8	NS 78a
1979	6.97 E+2	1.56 E+2	3.84 E-3	4.45 E-3	1.74 E-5	7.45 E-8	NS 79a

NOTES:
1. Station initial criticality occurred on December 1, 1973, and December 17, 1974.
2. For composition of noble gases in 1979, see Table 7.
3. Total halogens consist of I-131, I-133, and I-135.
4. Total particulates include only radionuclides with half-lives longer than eight days.

Table 7

Airborne Radionuclides Discharged at Prairie Island in 1979, Curie/year

RADIONUCLIDE	HALF-LIFE	RELEASE RATE		
		CONTINUOUS	BATCH	TOTAL
Gases				
H-3	12.3 y	-	-	1.56 E+2
C-14	5730 y	-	-	1.60 E+1
Ar-41	1.83h	2.41 E+0	2.43 E-1	2.65 E+0
Kr-85	10.7 y	0	1.30 E+0	1.30 E+0
Kr-85m	4.48h	7.41 E-1	6.47 E-2	8.06 E-1
Kr-87	76.3 m	1.96 E+0	5.15 E-1	2.48 E+0
Xe-131m	11.9 d	0	6.09 E-3	6.09 E-3
Xe-133	5.24d	4.40 E+2	2.28 E+2	6.68 E+2
Xe-133m	2.19d	5.06 E-1	1.34 E+0	1.85 E+0
Xe-135	9.09h	1.27 E+1	6.56 E+0	1.93 E+1
Iodine and Particulates				
I-131	8.06d	3.80 E-3	3.35 E-5	3.83 E-3
I-133	20.8 h	6.02 E-4	1.27 E-5	6.15 E-4
Co-58	70.8 d	4.44 E-6	0	4.44 E-6
Co-60	5.26y	8.42 E-7	0	8.42 E-7
Rb-88	17.8 m	0	4.37 E-6	4.37 E-6
Y-88	107 d	0	1.15 E-6	1.15 E-6
Ce-139	137 d	2.12 E-7	0	2.12 E-7
Ce-141	32.5 d	1.42 E-7	0	1.42 E-7
Ce-144	284 d	1.06 E-5	0	1.06 E-5

NOTES:
1. Values are from NS 79a.
2. C-14 was not measured but is an NRC generic default value (SD 76a).
3. Values for Rb-88, Y-88 and Ce-139 were not included as source terms in dose calculations. The latter two appear to be erroneous identifications by the analyst.
4. The following radionuclides were indicated as zero curie/year; Na-24, Mn-54, Co-57, Sr-85, Sr-89, Sr-90, Zr-95, Nb-95, Cd-109, Sb-124, Cs-134, Cs-137, Cs-138, Ba-140, Kr-88, Xe-135m, and Xe-138.

Table 8

Collective Dose Commitment Within Fifty Miles of the Prairie Island Nuclear Generating Plant in 1979, Computed by the Operator, Person-rem/year

PATHWAY/RADIONUCLIDE	TOTAL BODY	BONE	THYROID
By Pathway			
Plume	9.7 E-2 (1.2%)	9.7 E-2 (0.3%)	9.7 E-2 (1.2%)
Ground	4.1 E-5 (0.0%)	4.1 E-5 (0.0%)	4.1 E-5 (0.0%)
Inhalation	2.2 E-1 (2.8%)	1.2 E-4 (0.0%)	2.6 E-1 (3.1%)
Vegetables	4.3 E+0 (53.7%)	1.9 E+1 (54.7%)	4.5 E+0 (53.7%)
Cows' milk	1.8 E+0 (23.1%)	8.3 E+0 (24.2%)	2.0 E+0 (23.8%)
Meat	1.5 E+0 (19.1%)	7.1 E+0 (20.8%)	1.5 E+0 (18.2%)
Total	7.9 E+0	3.4 E+1	8.4 E+0
By Radionuclide			
H-3	9.7 E-1 (12.3%)	0.0 E+0 (0.0%)	9.7 E-1 (11.6%)
C-14	6.8 E+0 (86.5%)	3.4 E+1 (99.7%)	6.8 E+0 (82.0%)
Xe-133	9.3 E-2 (1.2%)	9.3 E-2 (0.3%)	9.3 E-2 (1.1%)
Other noble gases	4.1 E-2 (0.1%)	4.1 E-3 (0.0%)	4.1 E-3 (0.0%)
I-131	7.8 E-4 (0.0%)	1.1 E-3 (0.0%)	4.4 E-1 (5.2%)
Particulates	2.0 E-5 (0.0%)	4.4 E-5 (0.0%)	1.6 E-5 (0.0%)
Total	7.9 E+0	3.4 E+1	8.3 E+0

NOTES:
1. Other noble gases consist of Ar-41, Kr-85, Kr-85m, Kr-87, Xe-131m, Xe-133m and Xe-135; among these, ninety percent of the dose is due to Xe-135 and Ar-41.
2. The dose due to I-133 was computed to be less than 0.01 percent of the total.
3. Particulates consist of Co-58, Co-60, Ce-141, and Ce-144.
4. Doses to the GI tract, liver, kidney, lung, and skin are almost identical to the total body dose, although the individual pathway and radionuclide contributions differ slightly.
5. Data are from reference NS 80; estimated population is 2.1 million.

Table 9

Dose Commitment to Most Exposed Individuals Near the Prairie Island Nuclear Generating Plant in 1979, Computed by the Operator, mrem/year

PATHWAY	RADIONUCLIDE	TOTAL BODY	BONE	THYROID
Plume	Xe-133 and Xe-135	7.9 E-2 (88.5%)	7.9 E-2 (88.5%)	7.9 E-2 (88.5%)
	Other Xe and Kr	4.0 E-3 (4.4%)	4.0 E-3 (4.4%)	4.0 E-3 (4.4%)
	Ar-41	6.3 E-3 (7.1%)	6.3 E-3 (7.1%)	6.3 E-3 (7.1%)
	Total	8.9 E-2	8.9 E-2	8.9 E-2
Ground	Total	9.4 E-5	9.4 E-5	9.4 E-5
Inhalation	H-3	8.6 E-2 (99.9%)	0.0 E+0 (0.0%)	8.6 E-2 (74.2%)
	I-131	4.9 E-5 (0.1%)	8.6 E-5 (70.0%)	2.9 E-2 (24.9%)
	I-133	2.1 E-6 (0.0%)	4.6 E-6 (3.7%)	1.1 E-3 (0.9%)
	Ce-144	1.8 E-6 (0.0%)	3.2 E-5 (26.3%)	0.0 E+0 (0.0%)
	Total	8.6 E-2	1.2 E-4	1.2 E-1
Vegetables	H-3	4.6 E-1 (7.8%)	0.0 E+0 (0.0%)	4.6 E-1 (7.7%)
	C-14	5.4 E+0 (92.2%)	2.7 E+1 (100.0%)	5.4 E+0 (90.0%)
	I-131	1.5 E-4 (0.0%)	2.6 E-4 (0.0%)	8.5 E-2 (1.4%)
	Total	5.8 E+0	2.7 E+1	5.9 E+0
Cow's Milk		NONE		
Meat	H-3	2.7 E-2 (3.2%)	0.0 E+0 (0.0%)	2.7 E-2 (3.1%)
	C-14	8.4 E-1 (96.8%)	4.2 E+0 (100.0%)	8.4 E-1 (95.9%)
	I-131	1.4 E-5 (0.0%)	2.5 E-5 (0.0%)	8.3 E-3 (1.0%)
	Total	8.7 E-1	4.2 E+0	8.7 E-1
TOTAL		6.8 E+0	3.1 E+1	7.0 E+0

NOTES:
1. Location is 0.50 mi. SSE of plant, at dwelling with vegetable garden and meat animals, but no dairy cow or goat.
2. The highest annual off-site air doses were 0.5 mrad from gamma rays and 1.3 mrad from beta particles.
3. Calculated total doses to the GI tract, liver, kidney, lung and skin are similar to total body dose.
4. The calculated maximum dose is to the child; doses to adult and teenager are less.

Table 10

Environmental Radiological Monitoring Results Pertaining to Airborne Effluent at the Prairie Island Nuclear Generating Plant in 1979

SAMPLE TYPE (units)	TYPE AND NUMBER OF ANALYSES[a]		LLD[b]	INDICATOR LOCATIONS, MEAN (F)[c] AND RANGE	CONTROL LOCATIONS, MEAN (F) AND RANGE
TLD-quarterly (mrem/91 days)	Gamma	4-15	3.0	12.6 (8/8) (9.9-14.3)	15.3 (7/7) (10.1-19.5)
Air Particulates (pCi/m^3)	GB	4-217	0.002	0.037 (107/107) (0.005-0.105)	0.038 (110/110) (0.013-0.100)
Airborne Iodine (pCi/m^3)	I-131	3-155	0.02	LLD	LLD
Air Particulates Monthly composite of all locations (pCi/m^3)	GS	12		(12)	(0)
	Zr-95		0.002	LLD	NONE
	Cs-137		0.001	LLD	NONE
	Ce-144		0.004	LLD	NONE
Milk (pCi/l)	I-131	5-65	0.25	LLD	LLD
	Sr-89	3-24	1.3	LLD	LLD
	Sr-90	3-24		3.5 (12/12) (2.1-4.8)	4.1 (12/12) (3.1-5.1)
	GS	3-24		(12)	(12)
	Cs-137		2.8	4.2 (5/12) (2.9-4.7)	4.8 (4/12) (3.3-6.3)
Crops - cabbage (pCi/g wet)	I-131	2-2	0.008	LLD (1)	LLD (1)
Crops - corn (pCi/g wet)	GS	2-2		(1)	(1)
	Zr-95		0.027	LLD	LLD
	Cs-137		0.012	LLD	LLD
	Ce-144		0.63	LLD	LLD

Table 10 (continued)

SAMPLE TYPE (units)	TYPE AND NUMBER OF ANALYSES[a]		LLD[b]	INDICATOR LOCATIONS, MEAN (F)[c] AND RANGE	CONTROL LOCATIONS, MEAN (F) AND RANGE
Natural Vegetation (pCi/g wet)	I-131	3-6	0.03	LLD	LLD
	GS	3-6		(4)	(2)
	Zr-95		0.04	LLD	LLD
	Cs-137		0.03	LLD	LLD
	Ce-144		0.2	LLD	LLD
Topsoil (pCi/g dry)	Sr-90	9-9		0.10 (7/7) (0.07-0.14)	0.26 (2/2) (0.12-0.40)
	GS	9-9			
	Zr-95			LLD	LLD
	Cs-137		0.1	0.5 (7/7) (0.3-0.8)	1.1 (2/2) (0.8-1.4)
	Ce-144		0.25	LLD	LLD

NOTES: 1. a. GB = gross beta; GS = gamma scan; numbers show number of locations-number of samples.
b. LLD = lower limit of detection based on 3 sigma error for background sample.
c. Mean and range based upon detectable measurements only. Fraction of detectable measurements at specified locations is indicated in parentheses (F); second set of parentheses contains range.
2. Data are from NS 80b.

Table 11

Airborne Radioactive Releases Predicted for Appendix I Considerations, Curie/yr

RADIONUCLIDE	MONTICELLO	PRAIRIE ISLAND
H-3	2.1 E+1	6.6 E+2
C-14	9.5 E+0	1.6 E+1
Ar-41	2.5 E+1	5.0 E+1
Kr-83m	2.3 E+1	-
Kr-85	1.3 E+2	3.6 E+2
Kr-85m	1.1 E+2	1.0 E+1
Kr-87	2.8 E+2	2.0 E+0
Kr-88	3.8 E+2	1.8 E+1
Kr-89	6.0 E+2	-
Xe-131m	4.5 E+1	4.8 E+1
Xe-133	1.2 E+4	6.6 E+3
Xe-133m	2.9 E+1	5.6 E+1
Xe-135	1.2 E+3	3.8 E+1
Xe-135m	7.6 E+2	-
Xe-138	2.0 E+3	2.0 E+0
Total Noble Gas	1.8 E+4	7.1 E+3
I-131	7.7 E-1	1.3 E-1
I-133	2.3 E+0	1.9 E-1
Particulates	1.0 E-1	3.2 E-1

NOTES: 1. Totals and breakdown by source are given in references NS 76, NS 76a, NS 80c, and NS 80d, except that totals for C-14 and Ar-41 are given in references SD 76 and SD 76a; noble gas releases less than 1 Ci/yr were not listed.

2. Particulate release rates above 1.0 E-2 Ci/yr were given for Cr-51, Co-60, Cs-137 and Ba-140 at Monticello and for Mn-54, Fe-59, Co-58, Co-60, Cs-134, and Cs-137 at Prairie Island.

Table 12

Recently Published Transfer Parameters from Animal Feed to Human Food for Sr, I, Cs, and Pu, day/kg

ELEMENT	COW'S MILK	GOAT'S MILK	BEEF	PORK	CHICKEN	EGGS	REFERENCE
Strontium	1.4 E-3	-	3.0 E-4	2.9 E-3	3.2 E-2	2.2 E-1	LLL (Ng 79)
	2.9 E-3	-	3.0 E-3	7.3 E-3	-	-	Heidelberg (Br 79)
	1.2 E-3	-	-	-	-	-	ORNL (Ho 79)
	8.0 E-4	1.4 E-2	6.0 E-4	-	-	-	NRC (SD 77)
Iodine	9.9 E-3	-	7.2 E-3	2.7 E-2	2.0 E-1	4.0 E+0	LLL (Ng 79)
	1.0 E-2	4.7 E-1	2.0 E-2	9.0 E-2	-	-	Heidelberg (Br 79)
	1.0 E-2	3.3 E-1	-	-	-	-	ORNL (Ho 79)
	6.0 E-3	6.0 E-2	2.9 E-3	-	-	-	NRC (SD 77)
Cesium	7.1 E-3	-	2.0 E-2	3.0 E-1	4.0 E+0	4.3 E-1	LLL (Ng 79)
	1.2 E-2	-	1.0 E-1	2.6 E-1	-	-	Heidelberg (Br 79)
	6.7 E-3	-	1.1 E-2	-	-	-	ORNL (Ho 79)
	1.2 E-2	3.0 E-1	4.0 E-3	-	-	-	NRC (SD 77)
Plutonium	1.0 E-7	-	1.0 E-6	3.4 E-6	2.0 E-5	3.3 E-5	LLL (Ng 79)
	2.0 E-6	-	5.0 E-3	1.0 E-2	-	-	Heidelberg (Br 79)

NOTES:
1. LLL staff adapted these values from their assessment for the southeastern U. S.
2. Heidelberg staff utilized cited selected data for assessment at Wyhl, Germany.
3. ORNL value is the geometric mean of compiled data.

Table 13

Recently Published Transfer Parameters From Soil to Vegetation for Sr, I, Cs, and Pu, kg Dry Soil/kg Moist Vegetation

ELEMENT	GRASS (HAY)	CLOVER	LEAFY VEGETABLES (CABBAGE)	POTATOES	ROOT VEGETABLES	SWEET CORN	GRAINS (WHEAT, BARLEY)	REFERENCE
Strontium	7.2 E-1	-	8.0 E-2	6.0 E-2	-	1.1 E-2	2.7 E-1	LLL (Ng 79)
	3.2 E+0	7.2 E+0	2.5 E+0	7.5 E-1	1.5 E+1	-	1.7 E+0	Heidelberg (Br 79)
	1.7 E-2	-	1.7 E-2	-	-	-	-	NRC (SD 77)
Iodine	1.8 E-1	-	2.4 E-2	2.4 E-2	-	1.4 E-2	4.5 E-2	LLL (Ng 79)
	2.0 E-1	2.0 E-1	2.0 E-1	2.0 E-1	2.0 E-1	-	2.0 E-1	Heidelberg (Br 79)
	2.0 E-2	-	2.0 E-2	-	-	-	-	NRC (SD 77)
Cesium	1.4 E-1	-	4.0 E-3	2.0 E-2	-	8.1 E-3	4.5 E-2	LLL(Ng 79)
	5.9 E+0	8.5 E+0	7.5 E-1	1.5 E+1	7.0 E-2	-	4.8 E-1	Heidelberg (Br 79)
	1.0 E-2	-	1.0 E-2	-	-	-	-	NRC (SD 77)
Plutonium	9.0 E-4	-	1.2 E-4	1.2 E-3	-	5.4 E-4	1.8 E-3	LLL (Ng 79)
	1.0 E-1	1.0 E-1	1.0 E-1	1.0 E-1	1.0 E-1	-	1.0 E-1	Heidelberg (Br 79)

NOTES: 1. LLL staff adapted these values from their assessment for the southeastern U. S.
2. Heidelberg staff utilized cited selected data for assessment at Wyhl, Germany.

Table 14

Collective Dose Commitment Within 50 Miles of the Monticello Nuclear Generating Plant in 1977, Computed at PNL, Person-rem/year

Pathway	Radionuclide	Total Body	Bone	Thyroid
Plume	Kr-88 and Xe-138	7.5 E-2	7.5 E-2	7.5 E-2
	other Kr and Xe	3.5 E-2	3.5 E-2	3.5 E-2
	Total	1.1 E-1	1.1 E-1	1.1 E-1
Ground	Co-60	3.7 E-3	3.7 E-3	3.7 E-3
	other particulates	2.6 E-3	2.6 E-3	2.6 E-3
	Total	6.3 E-3	6.3 E-3	6.3 E-3
Inhalation	H-3	3.5 E-2	0.0 E+0	3.5 E-2
	C-14	8.1 E-3	4.3 E-2	8.1 E-3
	I-131	2.8 E-4	3.7 E-4	1.6 E-1
	I-133 and I-135	3.2 E-4	5.2 E-4	1.2 E-1
	others	7.1 E-4	7.8 E-3	0.0 E+0
	Total	4.4 E-2	5.2 E-2	3.2 E-1
Ingestion	H-3	2.9 E-2	0.0 E+0	2.9 E-2
	C-14	3.1 E-1	1.6 E+0	3.1 E-1
	Sr-90	8.3 E-3	3.4 E-2	0.0 E+0
	I-131	2.3 E-3	3.3 E-3	1.3 E+0
	others	1.6 E-2	1.7 E-2	6.6 E-3
	Total	3.7 E-1	1.7 E+0	1.6 E+0
Total		5.0 E-1	1.9 E+0	2.0 E+0

Notes: 1. Based on 1977 radionuclide release data plus C-14 generic default value, 1974 meteorological data, and 1970 population (2.0 million) (Ba 80).

2. Calculations were performed by D. A. Baker as described in Ba 79.

3. Doses to the GI tract, liver, kidney, lung, and skin are almost the same as the total body dose.

Table 15

Collective Dose Commitment within 50 Miles of the Prairie Island Nuclear Generating Plant in 1977, Computed at PNL, Person-rem/year

Pathway	Radionuclide	Total Body	Bone	Thyroid
Plume	Kr-88	1.4 E-1	1.4 E-1	1.4 E-1
	other Kr and Xe	1.2 E-1	1.2 E-1	1.2 E-1
	Ar-41	1.6 E-2	1.6 E-2	1.6 E-2
	Total	2.8 E-1	2.8 E-1	2.8 E-1
Ground	Co-60	2.4 E-4	2.4 E-4	2.4 E-4
	other particulates	2.7 E-4	2.7 E-4	2.7 E-4
	Total	5.1 E-4	5.1 E-4	5.1 E-4
Inhalation	H-3	2.6 E-2	0.0 E+0	2.6 E-2
	C-14	1.6 E-2	8.4 E-2	1.6 E-2
	I-131	3.4 E-5	4.7 E-5	2.0 E-2
	Others	2.7 E-5	5.0 E-4	5.9 E-4
	Total	4.2 E-2	8.5 E-2	6.3 E-2
Ingestion	H-3	1.6 E-2	0.0 E+0	1.6 E-2
	C-14	4.4 E-1	2.3 E+0	4.4 E-1
	I-131	2.6 E-4	3.8 E-4	1.5 E-1
	Others	5.5 E-4	8.9 E-4	3.5 E-5
	Total	4.6 E-1	2.3 E+0	6.1 E-1
Total		7.8 E-1	2.7 E+0	9.5 E-1

Notes:
1. Based on 1977 radionuclide release data plus C-14 generic default value, 1974 meteorological data, and 1970 population (2.0 million) (Ba 80).
2. Calculations were performed by D. A. Baker as described in Ba 79.
3. Doses to the GI tract, liver, kidney, lung, and skin are almost the same as the total body dose.

Table 16

Collective Dose Commitment within 50 Miles of
Prairie Island Nuclear Generating Plant in 1979
Computed with the AIRDOS-EPA Program, Person-rem/year

	Total Body	Bone (red Marrow)	Thyroid	Testes/Ovaries
By pathway				
Plume	2.2 E-4(0.0%)	3.4 E-5(0.0%)	2.4 E-5(0.0%)	2.2 E-5(0.0%)
Ground	1.2 E-4(0.0%)	1.4 E-5(0.0%)	1.0 E-5(0.0%)	1.3 E-5(0.0%)
Inhalation	5.5 E-2(1.8%)	5.5 E-2(1.1%)	5.5 E-2(3.1%)	5.5 E-2(3.2%)
Vegetables	1.3 E-0(41.9%)	1.9 E-0(39.6%)	8.8 E-1(49.9%)	8.3 E-1(48.8%)
Cow's Milk	9.2 E-1(29.7%)	1.5 E-0(31.2%)	5.0 E-1(27.8%)	4.5 E-1(26.5%)
Meat	8.0 E-1(25.8%)	1.4 E-0(29.2%)	3.8 E-1(21.1%)	3.3 E-1(19.4%)
Total	3.1 E-0	4.8 E-0	1.8 E-0	1.7 E-0
By radio-nuclide				
H-3	2.5 E-1(8.1%)	2.5 E-1(5.2%)	2.5 E-1(13.2%)	2.5 E-1(13.9%)
C-14	2.2 E-0(71.0%)	3.9 E-0(81.2%)	1.0 E-0(52.6%)	8.6 E-1(47.8%)
Xe-133	1.8 E-5(0.0%)	2.9 E-5(0.0%)	2.0 E-5(0.0%)	1.7 E-5(0.0%)
Other Noble Gases	4.1 E-6(0.0%)	5.3 E-6(0.0%)	3.9 E-6(0.0%)	4.8 E-6(0.0%)
I-131	6.5 E-1(21.0%)	6.5 E-1(13.5%)	6.5 E-1(34.2%)	6.5 E-1(36.1%)
Particulates	3.0 E-6(0.0%)	3.1 E-6(0.0%)	3.0 E-6(0.0%)	3.0 E-6(0.0%)
Total	3.1 E-0	4.8 E-0	1.9 E-0	1.8 E-0

Notes:
1. Other noble gases consist of Ar-41, Kr-85, Kr-85m, Kr-87, Xe-131m, Xe-133m, and Xe-135; among these, 85 percent of the dose is due to Xe-135 and Kr-87.
2. The dose due to I-133 was computed to be 1.4 E-3 person-rem/yr.
3. Particulates consist of Co-58, Co-60, Ce-141, and Ce-144.
4. Doses to the lungs, stomach wall, lower intestine wall, liver and kidneys are all somewhat less than the total body doses.
5. The same release rates, and exposure conditions were used as for Table 8.
6. The following doses to all organs were calculated due to:
   Sr-89, Sr-90, Cs-134, Cs-137, 1×10^{-5} Ci/yr each: 5.0 E-4 person-rem/yr
   Pu-239, 1×10^{-5} Ci/yr : 6.2 E-7 person-rem/yr
7. Calculations were performed by M. T. Ryan, ORNL

Table 17

Dose Commitment to Most Exposed Individuals Near the Monticello and Prairie Island Nuclear Generating Plants in 1979, Calculated From Environmental Monitoring Data

PATHWAY	RADIONUCLIDE	CONCENTRATION	ANNUAL INTAKE, pCi	DOSE COMMITMENT, mrem/year TOTAL BODY	BONE	THYROID
Plume and ground	Environmental	-	-	5.4 E+1	5.4 E+1	5.4 E+1
	from M or PI	-	-	<6.0 E+0	<6.0 E+0	<6.0 E+0
Inhalation ($3700\ m^3$/yr)	Sr-90	<0.002 pCi/m^3	< 7.4	<1.3 E-2	<2.0 E-1	-
	I-131	<0.02	< 74	<5.5 E-4	<9.6 E-4	<3.2 E-1
	Cs-137	<0.001	< 3.7	<1.3 E-4	<9.1 E-4	-
Vegetables - leafy (26 kg/yr)	I-131	<8 pCi/kg	<208	<2.0 E-3	<3.6 E-3	<1.2 E+0
Vegetables - total (546 kg/yr)	Cs-137	<20 pCi/kg	<10,900	<5.0 E-1	<3.6 E+0	-
Milk (330 l/yr)	Sr-90 fallout (M)	7 pCi/l	2,310	1.0 E+1	3.9 E+1	-
	fallout (PI)	4	1,320	5.7 E+0	2.2 E+1	-
	from M or PI	<3	< 990	<4.3 E+0	<1.7 E+1	-
	I-131	<0.25	< 83	<8.1 E-4	<1.4 E-3	<4.7 E-1
	Cs-137 fallout (M)	5	1,650	7.6 E-2	5.4 E-1	-
	fallout (PI)	3	990	4.6 E-2	3.2 E-1	-
	from M or PI	<4	<1,320	<6.1 E-2	<4.3 E-1	-
Meat - small game (41 kg/yr)	Cs-137 (M only)	<90 pCi/kg	<3,690	<1.7 E-1	<1.2 E+0	-

NOTES: 1. Concentrations are from Tables 5 and 10.
2. Annual intakes are from Table E-5 and dose factors are for child from Tables E-9 and E-13 in Ref. SD 77.
3. M: Monticello; PI: Prairie Island.

Table 18

Environmental Radiological Monitoring Results Obtained by the Wisconsin Department of Health and Social Services Pertaining to Airborne Effluent at the Prairie Island Nuclear Generating Plant in 1979

SAMPLE TYPE (Units)	TYPE AND NUMBER OF ANALYSES[a]		LLD[b]	INDICATOR LOCATIONS, MEAN (F) AND RANGE[c]	CONTROL LOCATIONS, MEAN (F) AND RANGE
Airborne Particulates (pCi/m^3)	GB	4-84	0.001	0.011 (21/21) (0.002-0.029)	0.013 (57/63) (0.001-0.084)
Airborne Particulates monthly composite (pCi/m^3)	GS Cs-137	4-36	0.005	0.008 (1/9)	0.007 (3/27) (0.006-0.008)
Milk (pCi/l)	I-131	3-24	3	LLD (12)	LLD (12)
	Sr-90	3-16	1	5.2 (8/8) (2.6-11)	5.2 (8/8) (3.9-6.2)
	Gs Cs-137	3-24	10	LLD (12)	LLD (12)
Vegetation (pCi/g dry)	GS Cs-137	8-8	3	LLD (3)	LLD (5)
Topsoil (pCi/g dry)	GS Cs-137	8-8	0.4	0.5 (3/3) (0.4-0.5)	0.9 (5/5) (0.5-1.5)

NOTES: 1. a. GB = gross beta; GS = gamma scan; numbers show number of locations-number of samples.
b. LLD = lower limit of detection based on 3 sigma error for background sample.
c. Mean and range based upon detectable measurements only. Fraction of detectable measurements at specified locations is indicated in parentheses (F).
2. Data are from He 80.
3. Air samples were collected until end of October. One gross beta sample collected for a single day (October 2-3) from the nearby and two distant stations had elevated levels due to insufficient decay of Rn-220 daughters.
4. In milk samples, I-131 LLD varied between 1 and 10 pCi/l; Sr-90 measurements are available until August.
5. Vegetation and topsoil samples were obtained July 6, 1979. Soil is from top three inches.

Table 19

Radionuclide Concentrations in Milk Measured
by the Minnesota Department of Health in 1979

LOCATION	RADIONUCLIDE CONCENTRATION, pCi/l		
	Sr-90	I-131	Cs-137
State-wide pasteurized milk network			
Minneapolis	3.7 (<2.1-6.2)	<3.0 (<1.6-<8.5)	4.0 (<1.5-6.1)
Little Falls	2.6 (<0.8-4.7)	<3.3 (<2.2-<4.9)	3.4 (<1.5-4.8)
Rochester	3.4 (<1.5-5.4)	<3.1 (<1.7-<6.4)	3.2 (<1.0-5.0)
All others	3.6 (<0.8-9.7)	<3.4 (<1.7-<14.0)	4.6 (<1.5-14.0)
Monticello area raw milk			
Indicator farm 2.5 mi NNE	5.8 (4.8-6.9)	<1.8 (<1.5-<2.6)	3.6 (<1.6-5.2)
Indicator farm 2.3 mi ESE	10.1 (5.3-13.0)	<2.0 (<1.4-<2.8)	7.4 (<5.0-10.0)
Control farm 11.5 mi NW	7.0 (5.6-9.0)	<2.0 (<1.4-<2.8)	7.8 (<4.8-13.0)
Prairie Island area raw milk			
Indicator farm 3.5 mi S	2.4 (<2.0-2.9)	<1.7 (<1.5-<1.9)	4.6 (2.2-6.6)
Indicator farm 2.2 mi SSE	2.6 (<0.8-4.5)	<1.6 (<1.4-<1.7)	3.0 (2.0-4.3)
Control farm (Schaeffer)	3.7 (<2.4-5.8)	<1.7 (<1.6-<1.8)	5.4 (3.2-8.7)

NOTES:
1. State-wide milkshed samples were collected and analyzed monthly; nuclear power station environmental raw milk samples were collected and analyzed in January, April, July, and October.
2. "All other" state-wide samples are from Bemidji, Duluth, Fergus Falls, Mankato, and Marshall; Little Falls and Minneapolis are nearest Monticello and Rochester and Minneapolis are nearest Prairie Island.
3. Some of the farms that provide raw milk samples near the stations are also sampled for the environmental monitoring program by the operator.
4. Average values and ranges (in parentheses) are given.

Table 20

Health Effects Calculated for the Maximum Exposed Individuals[a]

NUCLEAR STATION	TYPE OF DOSE	DOSE COMMITMENT mrem/yr	HEALTH EFFECTS FATAL CANCERS[b]	NONFATAL CANCERS[c]
Monticello	Whole body	0.2	4×10^{-8}	4×10^{-8}
	Most exposed organ (skin)	0.3	1×10^{-8}[d]	
Prairie Island	Whole body	7	1×10^{-6}	1×10^{-8}
	Most exposed organ (bone)	31	2×10^{-6}[d]	

NOTES:
a. Dose equivalents and collective dose equivalents are from this report, Section 2.5.
b. Risk estimates are from the BEIR Report (BE 72) to derive a central risk estimate according to the procedure used by the joint committee (Ba 80), namely 200 fatal cancers per 10^6 person-rem.
c. Estimate is based on the assumption that the total number of cancers is twice the number of fatal cancers.
d. Absolute risk estimates are from the BEIR Report (BE 72) and an assumption of an elevated risk period of seventy years; the risk estimate is one bone cancer per 10^6 person-rem.

Table 21

Health Effects Calculated for the Population Within Fifty Miles[a]

NUCLEAR STATION	TYPE OF DOSE	COLLECTIVE DOSE COMMITMENT person-rem/yr	HEALTH EFFECTS		
			FATAL CANCERS[b]	NONFATAL CANCERS[c]	GENETIC EFFECTS[e]
Monticello	Whole body	1.5	3×10^{-4}	3×10^{-4}	3×10^{-4}
	Most exposed organ (bone)	3.1	2×10^{-4}[d]		
Prairie Island	Whole body	7.9	2×10^{-3}	2×10^{-3}	2×10^{-3}
	Most exposed organ (bone)	34	2×10^{-3}[d]		

NOTES:
a. Dose equivalents and collective dose equivalents are from this report, Section 2.5.
b. Risk estimates are from the BEIR Report (BE 72) to derive a central risk estimate according to the procedure used by the joint committee (Ba 80), namely 200 fatal cancers per 10^6 person-rem.
c. Estimate is based on the assumption that the total number of cancers is twice the number of fatal cancers.
d. Absolute risk estimates are from the BEIR Report (BE 72) and an assumption of an elevated risk period of seventy years; the risk estimate is one bone cancer per 10^6 person-rem.
e. Genetic effects to all future generations are based on a birth rate of twenty per year per 1,000 people and using basic BEIR Report (BE 72) information as applied by the joint committee (Ba 80).